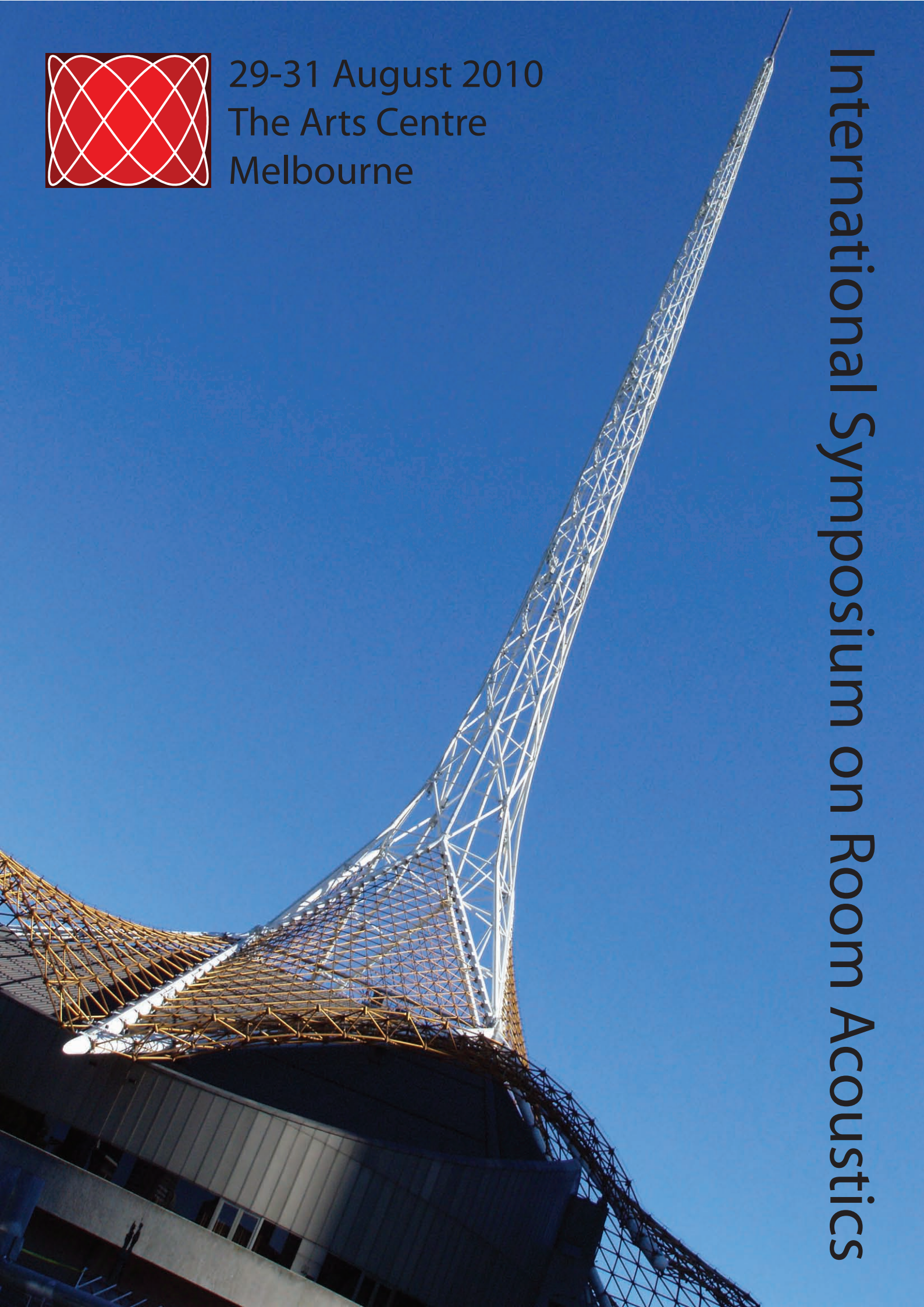
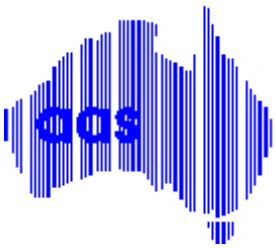
29-31 August 2010
The Arts Centre
Melbourne

International Symposium on Room Acoustics





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Preface

It is with great pleasure that the ISRA2010 Organising Committee and the Australian Acoustical Society welcome room acoustics researchers and practitioners from around the world to participate in the International Symposium on Room Acoustics (ISRA2010), an associated meeting of the 20th International Congress on Acoustics (ICA2010). This symposium is organised to continue the series of specialised symposia on room acoustics: in Edinburgh associated with ICA 1974 London; in Vancouver associated with ICA 1986 Toronto; in Hyogo associated with ICA 2004 Kyoto; and in Sevilla associated with ICA 2007 Madrid.

ISRA2010, like its predecessors, provides an important opportunity for room acoustics practitioners and researchers to learn from each other. While other conferences provide specialist sessions in aspects of acoustics of interest to those involved, smaller, more focussed and less formal meetings are often more productive. Without symposia such as ISRA2010, room acoustics would be the poorer and less able to face a future dominated by cheaper, bigger and more unusual buildings using new materials and construction methods, amongst other things.

That there is a need for more advances in the understanding of how sound behaves in rooms and how audiences/users perceive the acoustics of new and different spaces is not in doubt. What is in doubt is how this work will be supported. In difficult economic times research funding often suffers where there is not a strong economic incentive. If the room acoustics profession were interested in its future it may wish to broaden its crystal ball horizon to look into issues such as room acoustical cost benefit analysis, geriatric acoustics, drug induced changes in acoustical perception and perhaps even ergonomic acoustics (extending bimodal studies to include the effect of the comfort of seats on the perception of music). In this symposium there will, we hope, be adequate opportunity to discuss these and other ideas as well as more immediate issues that we face.

This is your symposium. We hope that you find it rewarding and challenging. It is a good opportunity to strike up new acquaintances or to meet friends and colleagues in a convivial atmosphere. We trust that you will also make the best of the city and venue and that you enjoy your stay in Melbourne.

Fergus Fricke

General Chair of ISRA2010

Norm Broner

President, Australian Acoustical Society

Symposium organisers

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Australian Acoustical Society President: Norm Broner
Conference Manager: Charles Don
Programme Chair: William Martens
Papers Chair: Densil Cabrera
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The papers that were accepted on the basis of peer-review are identified as such in the listing of abstracts.

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Financial Contributors

International Commission for Acoustics

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ICA Young Scientist Award

The International Commission for Acoustics provided funding to support young scientists to participate in ISRA2010. The awardees are:

Dr Joonhee Lee (now at Korea Institute of Construction Technology)

Dr Takuma Okamoto (Tohoku University, Sendai, Japan)

Dr Michelle Vigeant (University of Hartford, West Hartford, CT, USA)

Keynote speakers

Anders Christian Gade was awarded his MSc from the Technical University of Denmark (DTU) in 1977. Since then his main field of work has been auditorium acoustics: the conditions for performers on the stage, the relationships between hall geometry and the measureable acoustic properties and the potential effects of room acoustic enhancement systems. Lately he has also been engaged in how to deal with musicians' exposure to high sound levels, motivated by new EU rules. He has had a long career as researcher and associate professor at DTU (1979 - 2008); but also worked in consulting since 1984. Together with Bo Mortensen, he formed Gade & Mortensen Akustik in 2007. Since then he has devoted almost all his work hours to consulting. ACG is a frequent speaker in acoustics conferences and has written numerous papers on auditorium acoustics, among others the chapter on auditorium acoustic design in the recently issued Springer Handbook on Acoustics. ACG is a member of the EAA and a fellow of the Acoustical Society of America.

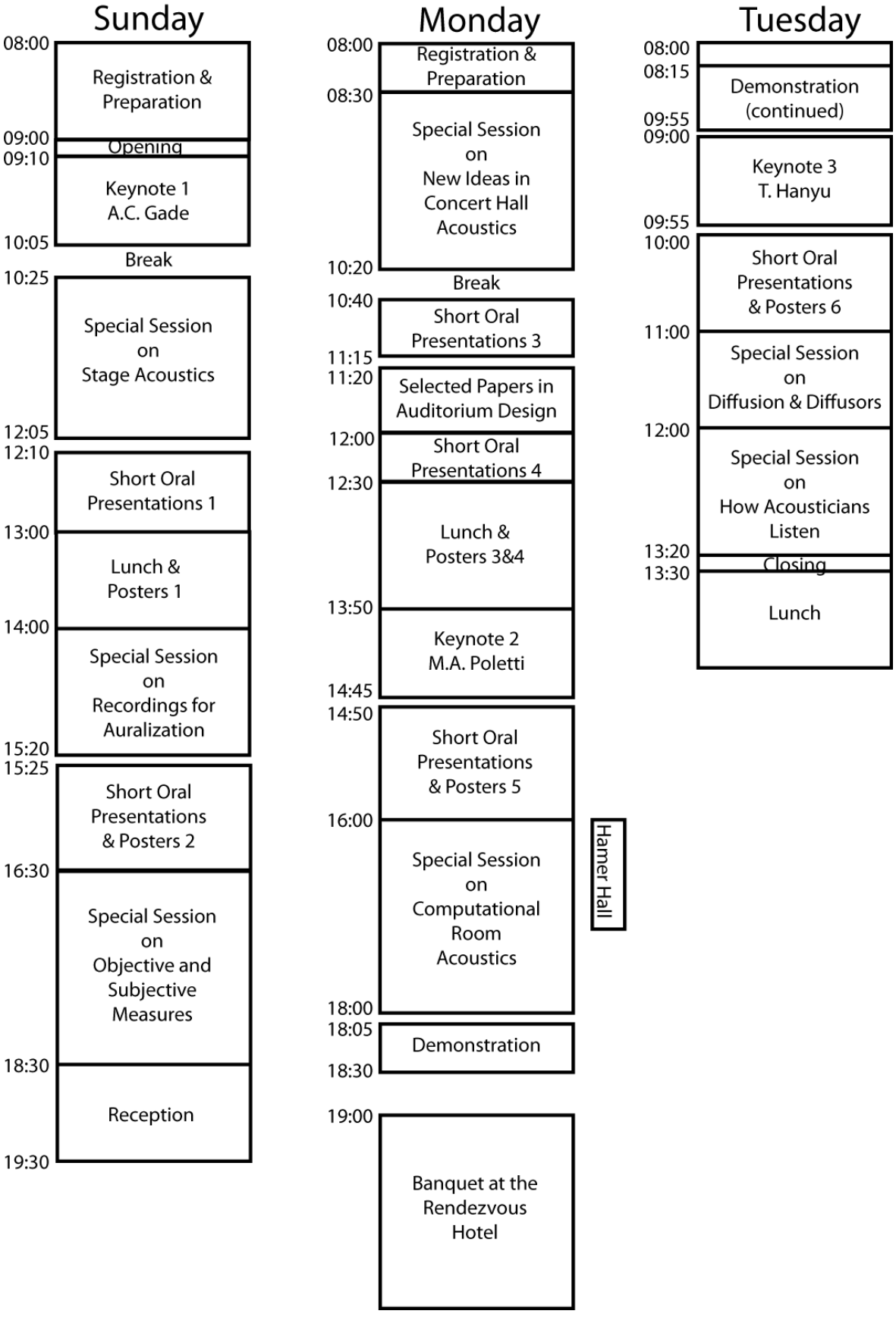
Mark Poletti received his Master of Science and PhD from the University of Auckland, New Zealand. He worked in Auckland University's Acoustics Research Centre for five years in acoustics testing and signal processing research. In 1989 he joined the DSIR communications group in Lower Hutt, New Zealand, and this group later became part of Industrial Research Limited. Here he developed the Variable Room Acoustics System (VRAS) for electroacoustic enhancement of room acoustics (now the technology behind the Meyer Constellation System). His current research interests include electroacoustic room enhancement, holographic sound recording and reproduction systems, virtual acoustics, and sonar and array signal processing.

Toshiki Hanyu is one of Japan's leading researchers in room acoustics. Born in 1965, he received his doctorate from Nihon University in 1993. He was a researcher in AV&C research institute of Panasonic, one of the largest electronic product manufacturers in the world, from 1990 until 1997 - where he developed the sound field control system. Now he is an Associate Professor of Nihon University and conducts research mainly on spatial impression of sound fields in concert halls. He has received the Young Investigator Award from the Architectural Institute of Japan in 1995, and the Excellent Research Award from Nihon University in 2006.

Banquet speaker

Leo L. Beranek is one of the best-known figures in acoustics. Born in 1914, he received his doctorate from Harvard University in 1940, and was Associate Professor of Communications Engineering at Massachusetts Institute of Technology from 1947 until 1958. He was the company president of Bolt Beranek and Newman (BBN) from 1952-71, then one of the world's largest acoustical consulting firms. His monographs on general acoustics and auditorium acoustics are classic texts in their fields. In recent years he has been the acoustical consultant for a number of auditoria in Tokyo. He has received numerous awards, including Gold Medals from the Acoustical Society of America, the Audio Engineering Society and the ASME, the U.S. President's National Medal of Science in 2003, and the Eta Kappa Nu Karapetoff Award in 2009. He is a visiting professor of the University of Sydney in 2010.

Programme overview



Detailed Programme

SUNDAY 29 AUGUST

08:00 **Registration**

09:00 **Opening**

09:10 **Keynote**

K1. Anders Christian Gade "Acoustics for symphony orchestras; status after three decades of experimental research"

10:05 **Break**

10:25 **Stage Acoustics (Chair: Anders Christian Gade)**

10:25 O1a. Jens Jørgen Dammerud, Michael Barron and Eckhard Kahle, "Objective assessment of acoustic conditions on concert hall stages – limitations and new strategies"

10:45 O1b. Kanako Ueno and Hideki Tachibana, "A consideration on acoustic properties on concert-hall stages"

11:05 O1c. John O'Keefe, "Reflection density and attenuation on stages and rehearsal halls"

11:25 O1d. Wei-hwa Chiang, Yi-run Chen, Chia-chun Chen and Yen-kun Hsu, "Stage acoustics for vineyard concert hall"

11:45 O1e. Wieslaw Woszczyk, Brett Leonard and Doyuen Ko, "Virtual stage acoustics"

12:05 **Break**

12:10 **Short Oral Presentations 1 (Chair: William Martens)**

Each short oral presentation timeslot is strictly limited to 3 minutes. Presenters should explain their corresponding poster during lunch.

P1a. Roberto Pompoli, Andrea Farnetani and Nicola Prodi, "A note on the acoustics of orchestra rehearsal rooms"

P1b. Hyung Suk Jang, Yong Hee Kim and Jin Yong Jeon, "Absorption of orchestra platform measured for the acoustical design of concert halls"

P1c. Margriet R. Lautenbach and Martijn L.S. Vercammen, "Stage acoustics: Renovation of the concert hall de Doelen, Rotterdam and other stages"

P1d. Carlos Jimenez-Dianderas, "Acoustical behaviour of colonial churches in Peruvian Andean Plateau (Puno, Peru)"

P1e. Joonhee Lee, Craig Schaefer, Hans-Elias de Bree and Ning Xiang, "Scaled-model measurements for coupled volumes using an automated high spatial-resolution scanning system"

P1f. Densil Cabrera, Doheon Lee, Ralph Collins, Bastian Hartmann, William L. Martens and Hayato Sato, "Characterising the variation in oral-binaural room impulse responses for horizontal rotations of a head and torso simulator"

P1g. Peng Jianxin and Bei Chengxun, "Prediction of Chinese speech intelligibility using useful to detrimental sound ratios based on auralization"

P1h. Mohamad Ngasri Dimon, Siti Dhalia Adzim Muhamod Adzim, Hasnizom Hassan and Mohd Zamri Jusoh, "Good speech intelligibility through novel acoustics material of geometric pattern perforated wall in medium size mosques"

P1i. Kenneth Roy and Sean Browne, "Classroom acoustics and green schools"

P1j. Yasushi Hoshino, Hayato Sato, Masayuki Morimoto and Yasuhiko Odagawa, "The relationship between sound insulation performance of walls and word intelligibility scores"

P1k. Maarten Luykx and Martijn Vercammen, "Natural speech intelligibility in theatres in relation to its acoustics"

P1l. Anna Magrini, Lucia Cattani and Lorenza Magnani, "A global index to evaluate the acoustical and thermal behavior of buildings"

P1m. Joo Young Hong, Pyoung Jik Lee, Byung Kwon Lee and Jin Yong Jeon, "Assessment of speech privacy in open plan offices"

P1n. David Borgeaud, "Secret room acoustics"

13:00 **Lunch and Posters 1**

14:00 **Recordings for Auralization (Chair: Michael Vorländer)**

14:00 O2a. Michelle C. Vigeant, Lily M. Wang, Jens Holger Rindel, Claus Lynge Christensen and Anders Christian Gade "Multi-channel orchestral anechoic recordings for auralizations"

14:20 O2b. Ron Freiheit, "Creating an anechoic choral recording"

14:40 O2c. Martin Pollow and Gottfried Behler, "Directional database for musical instruments to be used for acoustical VR"

15:00 O2d. Jukka Pätynen and Tapio Lokki, "Evaluation of concert hall auralization with virtual symphony orchestra"

15:20 **Break**

15:25 **Short Presentations and Posters 2 (Chair: William Martens)**

Each short oral presentation timeslot is strictly limited to 3 minutes. Presenters should explain their corresponding poster in the second half of the session.

P2a. Timothy Gulsrud, "Loudspeaker simulation of a string quartet for *in situ* listening evaluation"

P2b. Young-ji Choi, Jin-Hak Lee, Hyun-Kyung Joo and Daeup Jeong, "Effect of sample size on measurement of the absorption by seats"

P2c. Chiung Yao Chen, Kuo Feng Hung and Jui Ling Chen, “Study of evaluating Indoor noisiness in hospitals under temporal varieties using autocorrelation analysis”

P2d. Martijn Vercammen, “Improving the accuracy of sound absorption measurement according to ISO 354”

P2e. Sakari Tervo, Teemu Korhonen and Tapio Lokki, “Estimation of reflections from impulse responses”

P2f. Lamberto Tronchin and Milo Coralli, “The acoustic design proposed for a church’s transformation into auditoria”

P2g. Jin You, Jeong Jun Kim and Jin Yong Jeon, “Effects of absorption elements and stage set on the stage house acoustics in a proscenium hall”

P2h. Ingo Witew, Pascal Dietrich, Michael Vorländer and Diemer de Vries, “Uncertainty of room acoustical measurements – How many measurement positions are necessary to describe the conditions in auditoria?”

P2i. Fabio Figueiredo and Jean-Dominique Polack, “Variations on acoustical measurement procedures and their influence on acoustical parameters”

The poster session includes refreshments

16:30 **Objective and Subjective Measures (Chairs: Brian F.G. Katz & Eckhard Kahle)**

16:30 O3a. John Bradley, “Review of objective room acoustics measures and future needs”

16:50 O3b. Alban Bassuet, “New acoustical parameters and visualization techniques to analyze the spatial distribution of sound in music spaces”

17:10 O3c. Tapio Lokki, Heikki Vertanen, Antti Kuusinen, Jukka Pätynen and Sakari Tervo, “Auditorium acoustics assessment with sensory evaluation methods”

17:30 O3d. Harold Marshall, Thomas Scelo and Peter Exton, “Whole stage imaging for the control of sound strength in concert halls”

17:50 Panel discussion

18:30 **Reception**

MONDAY 30 AUGUST

08:00 Registration & Preparation

08:30 **New Ideas in Concert Hall Acoustics (Chair: Leo L. Beranek)**

Panel discussion, with contributions from Yasuhisa Toyota, R. Lawrence Kirkegaard, Harold Marshall, Anders Christian Gade, Alban Bassuet and Leo L. Beranek (chair)

10:20 **Break**

10:40 **Short Presentations 3 (Chair: William Martens)**

Each short oral presentation timeslot is strictly limited to 3 minutes. Presenters should explain their corresponding poster during lunch.

P3a. Rob Harris, "Auditorium acoustic design: 30 years, 15 projects"

P3b. Lamberto Tronchin, "The reconstruction of the Teatro Galli in Rimini: the acoustic design"

P3c. Timothy Gulsrud, Peter Exton, Arthur van der Harten and Larry Kirkegaard, "Room acoustics investigations in Hamer Hall at the Arts Centre, Melbourne"

P3d. Zuhre Su Gul and Mehmet Caliskan, "Acoustical considerations in the design of Heydar Aliyev Center Auditorium"

P3e. Motoo Komoda, Ayako Hakozaki and Yasuhisa Toyota, "Acoustical design of new Danish Radio concert hall"

P3f. Wei-hwa Chiang, Wei Lin, I-Te Yeh and Yen-kun Hsu, "A mid-size concert hall with staggered terraced seating"

P3g. Hyo Joo Yoo, Chun Ki Seo, Jae Ho Kim and Jin Yong Jeon, "Acoustical renovation of large auditorium to enhance sound strength and IACC"

P3h. Jae Ho Kim, Chun Ki Seo, Hyo Joo Yoo and Jin Yong Jeon, "The effect of reflectors on sound strength (G) and IACC in a fan-shape hall"

P3i. Steve Ellison and Roger Schwenke, "The case for widely variable acoustics"

11:15 **Break**

11:20 **Selected Papers in Auditorium Design (Chair: Fergus Fricke)**

11:20 O4a. Alban Bassuet, "The acoustical design of the new national opera house of Greece"

11:40 O4b. Hideo Miyazaki, Shinjiro Yamashita, Yasushi Shimizu, Yoshihide Shiba and Ami Tanaka, "The acoustical design of the new Yamaha Hall"

12:00 **Short Presentations 4 (Chair: William Martens)**

Each short oral presentation timeslot is strictly limited to 3 minutes. Presenters should explain their corresponding poster during lunch.

P4a. Doheon Lee, Densil Cabrera and William L. Martens, "Equal reverberance contours for synthetic room impulse responses listened to directly: Evaluation of reverberance in terms of loudness decay parameters"

P4b. Jasper van Dorp Schuitman and Diemer de Vries, “An artificial listener for assessing content-specific objective parameters related to room acoustical quality”

P4c. Chungeun Kim, Russell Mason and Tim Brookes, “A quasi-binaural approach to head-movement-aware evaluation of spatial acoustics”

P4d. Michelle C Vigeant, Robert D Celmer and David A Dick, “Investigation of the correlation between late lateral sound level and total acoustic absorption, and an overview of a related subjective study”

P4e. Yuki Matsumoto, Masahiro Suzuki, Hisako Ogushi and Akira Omoto, “Application of auditory filter for evaluation of sound and sound field”

P4f. Yong Hee Kim, Hyo Joo Yoo and Jin Yong Jeon, “Perception of scattered sounds in rectangular concert halls”

P4g. Densil Cabrera, Takuma Okamoto, Brian F.G. Katz, Markus Noisternig, Yukio Iwaya and Yo-iti Suzuki, “Considerations in characterising an almost anechoic room for interactive spatial audio reproduction”

P4h. Dirk Schröder, Frank Wefers, Sönke Pelzer, Dominik Rausch, Michael Vorländer and Torsten Kuhlen, “Virtual reality system at RWTH Aachen University”

12:30 **Lunch and Posters 3&4**

13:50 **Keynote**

K2. Mark A. Poletti, “Active acoustic systems for the control of room acoustics”

14:45 **Break**

14:50 **Short Presentations and Posters 5 (Chair: William Martens)**

Each short oral presentation timeslot is strictly limited to 3 minutes. Presenters should explain their corresponding poster in the second half of the session.

P5a. Takayuki Watanabe and Masahiro Ikeda, “Improvement of the acoustics under the balcony in auditoria using the electro-acoustic method - A study with a full-scale model”

P5b. Deep Sen, Shuai Wang and Qingqing Meng, “Soundfield synthesis with spatio-temporal compensation”

P5c. Csaba Huszty, Sakae Yokoyama and Shinichi Sakamoto, “Application of analytic sweep segments in room acoustic measurements”

P5d. Andrew Wabnitz, Nicolas Epain, Craig Jin and André van Schaik, “Room acoustics simulation for multichannel microphone arrays”

P5e. Roger Schwenke and Steve Ellison, “Objective assessment of active acoustic system performance”

P5f. Robert Anderssohn, Steffen Marburg and Hans-Juergen Hardtke, “Identification of admittance parameters in arbitrarily shaped interiors based on sound pressure measurements using a 3d-FEM-based inverse algorithm”

P5g. Jung Su Kim, Jin Hak Lee, Young Ji Choi and Daeup Jeong, “The effect of an edge on the measured scattering coefficients in a reverberation chamber based on ISO 17497-1”

P5h. Samuel Siltanen, Tapio Lokki and Lauri Savioja, “Room acoustics modeling with acoustic radiance transfer”

The poster session includes refreshments

16:00 **Computational Room Acoustics (Chair: Uwe M. Stephenson)**

16:00 O5a. Samuel Siltanen, Tapio Lokki and Lauri Savioja, “Rays or waves? Understanding the strengths and weaknesses of computational room acoustics modeling techniques”

16:20 O5b. Uwe M. Stephenson, “Introducing higher order diffraction into beam tracing based on the uncertainty relation”

16:40 O5c. Alexander Pohl and Uwe M. Stephenson, “A combination of the sound particle simulation and the radiosity method”

17:00 O5d. Anish Chandak, Lakulish Antani, Micah Taylor and Dinesh Manocha, “Fast and accurate geometric sound propagation using visibility computations”

17:20 O5e. Lauri Savioja, Dinesh Manocha and Ming C. Lin, “Use of GPUs in room acoustic modeling and auralization”

17:40 O5f. Jens Holger Rindel, “Room acoustic modelling techniques: A comparison of a scale model and a computer model for a new opera theatre”

18:00 **Break**

18:05 **Demonstration**

O6. David Griesinger, “The relationship between audience engagement and the ability to perceive pitch, timbre, azimuth and envelopment of multiple sources” (to be continued Tuesday morning)

18:30 **Break**

19:00 **Banquet at the Rendezvous Hotel**

TUESDAY 31 AUGUST

08:00 **Preparation and Demonstration**

08:15 David Griesinger, "The relationship between audience engagement and the ability to perceive pitch, timbre, azimuth and envelopment of multiple sources" (continued from Monday)

08:55 **Break**

09:00 **Keynote**

K3. Toshiki Hanyu, "A framework for characterizing sound field diffusion based on scattering coefficient and absorption coefficient of walls"

09:55 **Break**

10:00 **Short Presentations and Posters 6 (Chair: William Martens)**

Each short oral presentation timeslot is strictly limited to 3 minutes. Presenters should explain their corresponding poster in the second half of the session.

P6a. Dirk Schröder, U. Peter Svensson and Michael Vorländer, "Open measurements of edge diffraction from a noise barrier scale model"

P6b. Fausto E. Rodriguez-Manzo and Elisa Garay-Vargas, "The role of sound diffusing surfaces in the quality of the architectural space"

P6c. James Heddle, "Real-valued amplitude reflection grating designs for sound diffusion"

P6d. Jie He and Jian Kang, "Architectural and acoustic features of the caisson ceiling in traditional Chinese theatres"

P6e. Chun Ki Seo, Yong Hee Kim, Pyoung Jik Lee and Jin Yong Jeon, "Acoustical renovation of small auditoria using sound diffusers"

P6f. Lamberto Tronchin and Valerio Tarabusi, "The acoustic design of the Teatro Eschilo, Gela (Italy)"

The poster session includes refreshments

11:00 **Diffusers and Diffusion (Chair: Jin Yong Jeon)**

11:00 O7a. Isabelle Schmich and Nathalie Brousse, "*In situ* measurement methods for characterising sound diffusion"

11:20 O7b. Javier Redondo, Rubén Picó and Víctor Sánchez-Morcillo, "The potential for phononic sound diffusers (PSD)"

11:40 O7c. Jin Yong Jeon, Yong Hee Kim and Hyung Suk Jang, "Diffuser design in concert halls using scale models"

12:00 **How Acousticians Listen (Chair: Pamela Clements)**

O8. Panel discussion, with contributions from Leo L. Beranek, J. Christopher Jaffe (*in absentia*), Tateo Nakajima, Eckhard Kahle, R. Lawrence Kirkegaard and Pamela Clements (chair)

13:20 **Closing**

13:30 **Lunch**

List of Abstracts (chronological order)

Acoustics for symphony orchestras; status after three decades of experimental research
Anders Christian Gade (Gade & Mortensen Akustik A/S, Copenhagen, Denmark)
Keynote address, K1
In 1978, one particular paper in JASA by Harold Marshall, D. Gottlob and H. Alrutz titled: "Acoustical conditions preferred for ensemble" inspired the author and other researchers to investigate the acoustic conditions experienced by musicians on concert hall stages. The research carried out since then has involved subjective assessment by musicians playing in simulated sound fields as well as in real halls; but also purely objective investigations have been re-ported. After one third of a century, it seems appropriate to summarize what we have learned and where we still need more knowledge. The paper will summarize major contributions to the field, discuss the differences in opinion in view of the limitations associated with different experimental approaches, and finally address the challenges related to meeting working environment requirements recently enforced by law in Europe for limiting the sound exposure levels of musicians.

Objective assessment of acoustic conditions on concert hall stages – limitations and new strategies
Jens Jørgen Dammerud (Nordåsveien 65, 1251 Oslo, Norway)
Michael Barron (Department of Architecture & Civil Engineering, University of Bath, BA2 7AY, UK)
Eckhard Kahle (Kahle Acoustics, 188 Avenue Molière, 1050 Brussels, Belgium)
Invited paper (peer-reviewed): Special session on Stage Acoustics, O1a
At present the most common measures for assessing stage acoustic conditions on concert hall stages are the Support measures – ST_{early} and ST_{late}. These measures are based on monophonic omnidirectional responses obtained at 1 m from the sound source, on a stage without a full symphony orchestra (or similar group of people) present. Both objective and subjective studies have been conducted, the latter using questionnaires with several orchestras and dialogue with musicians. Objective studies involved measurements on real stages of the Support measures and other acoustic measures such as *T*, *EDT*, C_{80}, G_{7-50}, G_e (G_{0-80}) and G_l ($G_{80-\infty}$) as well as a set of proposed architectural measures. These have been complemented with analytical as well as scale and computer model investigations into sound behaviour on both empty and occupied concert stages. The major results from these studies are presented in this paper along with a discussion of alternative approaches for assessing stage acoustic conditions. One important result concerned the relevance of directions from which early reflections arrive regarding perceived ensemble conditions, an objective factor not assessed by the Support measures.

A consideration on acoustic properties on concert-hall stages
Kanako Ueno (Meiji University, Higashimita 1-1-1, Tama-ku, Kawasaki, Kanagawa, Japan)
Hideki Tachibana (Chiba Institute of Technology, Tsudanuma 2–17–1, Narashino, Chiba, Japan)
Invited paper (peer-reviewed): Special session on Stage Acoustics, O1b
This paper discusses acoustic properties that musicians experience on a concert hall stage; the discussion is based on the authors' experience gained from conducting experimental studies using a three dimensional sound field simulation technique. First, the experimental findings on the relationship between the acoustic requirements of musicians and acoustic conditions such as early reflection and reverberation are reviewed. Second, the validity and problems of stage acoustic indices ST_{early}, ST_{late}, and *EEL* are addressed. In addition, unsolved issues with regard to musicians' requirements during their performance are considered and problems requiring future study are pointed out.

Reflection density and attenuation on stages and rehearsal halls

John O'Keefe (Aercoustics Engineering Limited, 50 Ronson Drive, #165, Toronto Canada)

Invited paper (peer-reviewed): Special session on Stage Acoustics, O1c

A novel method of counting reflections and reflection density is presented. The method is borrowed from non-linear studies of fractal systems where time delayed versions of a signal are plotted against each other. In this case, the sound pressure $p(t)$ of an impulse response function is plotted against its time derivative, dp/dt. Each resulting circle represents a reflection. Reflection counts are much lower than would be expected from theoretical predictions. In this study they're primarily in the hundreds rather than thousands. This tool was then used to study measurements on 25 stages and rehearsal halls. Previous work by the author demonstrated that sound levels on stage attenuate in a linear fashion, with regression coefficients in the range of 0.9. The hypothesis of the current study was that linear regression analysis might be a better predictor of sound levels on a stage than Revised Theory. The reasons for this are primarily the proximity of the sound source and early reflecting surfaces. In stage impulse response functions, where non-diffuse early energy is stronger than it is in the audience, the assumption of diffuse sound has been violated; hence the inappropriateness of the reverberant field theory that Revised Theory is based on. The study's hypothesis has proved incorrect, at least partially. Revised Theory is indeed a good predictor of sound levels on stage, provided that the direct sound is included. When the direct sound is eliminated, which is not uncommon on an occupied stage, linear regression is a better predictor of sound levels.

Stage acoustics for vineyard concert hall

Wei-hwa Chiang (National Taiwan University of Science and Technology 43, Keelung Rd. Section 4, Taipei 106, Taiwan, R.O.C)
Yi-run Chen (National Taiwan University of Science and Technology 43, Keelung Rd. Section 4, Taipei 106, Taiwan, R.O.C)
Chia-chun Chen (National Taiwan University of Science and Technology 43, Keelung Rd. Section 4, Taipei 106, Taiwan, R.O.C)
Yen-kun Hsu (National Taiwan University of Science and Technology 43, Keelung Rd. Section 4, Taipei 106, Taiwan, R.O.C)

Invited paper: Special session on Stage Acoustics, O1d

In rectangular concert halls all surfaces near the stage can be valuable for acoustical communication among performers, while in a vineyard hall the ceiling may become the only surface to provide early reflections back to the stage. Field measurement and subjective evaluation in a hall with adjustable overhead panels were performed regarding the effectiveness of the reflectors for various parts of an orchestra. Results of computer modeling were presented that compares various design features intended for enhancing early and late energy back to the performers. Also presented were the discussion regarding the interaction between the parameters for the musician and the parameters for the audience.

Virtual stage acoustics: A flexible tool for providing useful sounds for musicians

Wieslaw Woszczyk (CIRMMT, Schulich School of Music, McGill University, Montreal, Canada)
Doyuen Ko (CIRMMT, Schulich School of Music, McGill University, Montreal, Canada)
Brett Leonard (CIRMMT, Schulich School of Music, McGill University, Montreal, Canada)

Invited paper: Special session on Stage Acoustics, O1e

Musicians performing on stage require an appropriate balance of sounds from all instruments and voices, including their own, to achieve a good sense of ensemble. The balance normally depends on the stage set up, properties of the instruments, and the availability of surfaces redirecting the sounds back to the musicians. It is possible, using virtual acoustics technology, to modify the balance of sounds heard by

musicians and to enhance their self- and mutual audibility on stage. The paper presents the results of experiments conducted with musicians immersed in virtual acoustics receiving adjustable amounts of stage support from early, mid, and late parts of the sound field projected from multiple angles around the ensemble. The importance of the relative balance between the direct sound and reverberation, the loudness level of support and the projection angles are evaluated, including the effects of simulated stage and hall. It is conceivable to create a shared performance space where musicians and audiences experience similar auditory sensations and where communication between the artist and the audience becomes more immediate and intimate.

A note on the acoustics of orchestra rehearsal rooms
Roberto Pompoli (Engineering Department (ENDIF), University of Ferrara, Italy)
Nicola Prodi (Engineering Department (ENDIF), University of Ferrara, Italy)
Andrea Farnetani (Engineering Department (ENDIF), University of Ferrara, Italy)
Contributed paper (peer-reviewed), P1a
The acoustical conditions of rehearsal rooms are of primary importance during the training process of an orchestra. Therefore these spaces should be specifically designed to allow the musicians to clearly hear themselves and each other. At the same time an appropriate sound level should be maintained to avoid extensive exposure to high pressure levels. Despite the peculiar role of these rooms in the musical production process, acoustic design criteria are not still sufficiently clarified. This paper deals with a description of a design process which, staring from simple formulas of a reverberant field, leads to investigate the relevance of geometrical and acoustical parameters on the final performance of a rehearsal room. The influence of the values of the ratio V/N (Volume/Number of musicians), S/N (floor surface/number of musicians), W/N (Sound power/Number of musicians) on objective acoustic parameters such as ST_{Early} (Early support) will be described. A guide line for the acoustic design of an orchestra rehearsal room will be finally proposed. Some specific case histories of rehearsal rooms will be discussed.

Absorption of orchestra platform measured for the acoustical design of concert halls
Hyung Suk Jang (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Yong Hee Kim (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Jin Yong Jeon (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Contributed paper, P1b
The absorption of an orchestra on various orchestra platforms was measured using scale model concert halls. The acoustical characteristics for both stage and audience areas were examined as a function of stage absorption by varying the number of orchestral players. From the measurements, it was found that large orchestra increases absorption on stage and so reduces RT for the audience up to 0.1 s with linear relationship to the number of players; EDT decreased at an even higher rate, and sound strength (G) was also reduced by 0.3 dB. Computer modeling for the occupied stage condition was undertaken to acoustically match the scale model results.

Stage acoustics: Renovation of the concert hall de Doelen, Rotterdam and other stages
Margriet R. Lautenbach (Peutz bv, Zoetermeer, the Netherlands)
Martijn L.S. Vercammen (Peutz bv, Mook, the Netherlands)
Contributed paper, P1c
When opened in 1966, the main concert hall in De Doelen, was fitted with six canopies above the stage platform, which were removed only six years later. During the design process of the renovation from 2007

to 2009, possibilities to re-introduce a stage canopy and influences of shape and materials are investigated. Objective acoustic parameters obtained by carrying out measurements in the hall are examined and compared to the results of several questionnaire rounds which gave an impression about the musicians' subjective judgement about the stage acoustics in De Doelen and two other halls. From comparison between subjective research and measurements it was concluded that increasing support (ST1) and Early Reflections Strength (G5-80) would be required to improve stage conditions. The Early Reflections Strength (G5-80) is not a standardized parameter but might be proposed for ensemble conditions. The influence of the proposed stage reflector is investigated in a 1:10 scale model and by calculations with a ray-tracing computer model. The renovation of De Doelen is completed in September 2009. This article gives an overview of the investigations and the final measured objective and subjective results of the stage acoustics in De Doelen. In spring 2010 a similar investigations on stage acoustics has taken place in the Maurice Ravel Auditorium Lyon, of which the results also are incorporated in the paper.

Acoustical behaviour of colonial churches in Peruvian Andean Plateau (Puno, Peru)
Carlos R. Jiménez-Dianderas (Departamento de Arquitectura, Pontifica Universidad Católica del Perú, Av. Universitaria 1801, Lima 32, Peru)
Manuel Recuero López (INSIA, Universidad Politécnica de Madrid, Carretera de Valencia Km.7, 28031 Madrid, Spain)
Contributed Paper, P1d
The paper searches for characterizing the acoustical behavior of nine colonial churches in Puno, a southern city of Peru, surrounding the Titicaca Lake in the Andean Plateau. The Peruvian Andean Plateau was an important extended area through the Spaniard Colonial Era in Peru due to the extractive mining activity of the zone, so several religious orders established in the area and fix the European styles and building process to the geography, geology and available building materials. Through five typical acoustical objective parameters it is defined the acoustical environment in each church. A comparison between several positions in each church analyzed and among churches will be presented.

Scaled-model measurements for coupled volumes using an automated high spatial-resolution scanning system
Joonhee Lee (Graduate Program in Architectural Acoustics, School of Architecture, Rensselaer Polytechnic Institute, Troy, NY, USA)
Craig Schaefer (Graduate Program in Architectural Acoustics, School of Architecture, Rensselaer Polytechnic Institute, Troy, NY, USA)
Hans-Elias de Bree (Microflown Technologies, Arnhem, Netherlands)
Ning Xiang (Graduate Program in Architectural Acoustics, School of Architecture, Rensselaer Polytechnic Institute, Troy, NY, USA)
Contributed paper, P1e
This paper presents an experimental study of low frequency behavior in coupled volumes. In order to examine low frequency behavior in coupled volumes, an eighth-scale model of two coupled volumes with an automated high spatial-resolution scanning system has been developed. The validation of the system on spatial resolution and reverberation times are examined before measurements. The validated scanning system makes it possible to acquire thousands of room impulse responses on a designated planar grid with a fine grid size in the scaled model. The high spatial-resolution scanning results are used to investigate the characteristics of acoustic wave propagation in both single-space and coupled-volume systems. Temporal behaviors of sound pressure propagations in the scaled model will be demonstrated with integrated measurements in both rooms. The results will show diffraction through aperture opening and reflection phenomena in the system. Scanning results with an acoustic particle velocity sensor will visualize sound energy flows between coupled-volume systems. The directions and magnitudes of sound energy flows are

represented with two dimensional vector arrows. The presented scanning results are highly dependent on variable coupling aperture sizes and frequencies. This paper also discusses some design issues relevant to high quality, high spatial resolution scanning, to diffusely reflecting interior surfaces.

Characterising the variation in oral-binaural room impulse responses for horizontal rotations of a head and torso simulator
Densil Cabrera (Faculty of Architecture, Design & Planning, University of Sydney, NSW 2006, Australia)
Doheon Lee (Faculty of Architecture, Design & Planning, University of Sydney, NSW 2006, Australia)
Ralph Collins (Faculty of Architecture, Design & Planning, University of Sydney, NSW 2006, Australia)
Bastian Hartmann (Faculty of Architecture, Design & Planning, University of Sydney, NSW 2006, Australia)
William L. Martens (Faculty of Architecture, Design & Planning, University of Sydney, NSW 2006, Australia)
Hayato Sato (Environmental Acoustics Laboratory, Kobe University, Rokkodai, Nada, Kobe, Japan)
Contributed paper (peer-reviewed), P1f
Oral-binaural room impulse responses (OBRIRs) describe the room acoustical response from the mouth to the ears of a head or dummy head. In this study, we measured OBRIRs in ten rooms, ranging from small to large. In each room, a head and torso simulator (HATS) was rotated at 2 degree increments to sample the room response at the selected measurement position. In rotating the HATS, the radiation pattern of the mouth rotates with the reception pattern of ears. This paper characterises the variation in room gain and interaural response of the tested rooms, and in doing so, we consider how OBRIRs can be usefully understood in terms of acoustical parameters.

Prediction of Chinese speech intelligibility using useful to detrimental sound ratios based on auralization
Peng Jianxin (Department of Physics, School of Science, South China University of Technology, Guangzhou, China; State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou, China)
Bei Chengxun (State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou, China)
Contributed paper (peer-reviewed), P1g
The subjective Chinese speech intelligibility scores are obtained by using the simulated binaural room impulse responses based on auralization technique. The simulated binaural room impulse responses are first convolved with the Chinese phonetically balanced test word lists signals recorded in an anechoic chamber, then reproduced over headphone. The relationship between subjective Chinese speech intelligibility scores and the objective acoustical parameter useful-to-detrimental sound ratio is studied and analysed in simulated rooms. There is high correlation between Chinese speech intelligibility scores and the useful-to-detrimental sound ratio. The useful-to-detrimental sound ratio can evaluate and predict Chinese speech intelligibility in rooms.

Good speech intelligibility through novel acoustics material of geometric perforated panel in mosques
Mohamad Ngasri Dimon (Universiti Teknologi Malaysia, Johor, Malaysia)
Siti Dhalia Adzim (Universiti Teknologi Malaysia, Johor, Malaysia)
Muhamod Adzim (Universiti Teknologi Malaysia, Johor, Malaysia)
Hasnizom Hassan (Universiti Teknologi Malaysia, Johor, Malaysia)
Nor Azliz (Universiti Teknologi Malaysia, Johor, Malaysia)
Mohd Zamri Jusoh (Universiti Teknologi Malaysia, Johor, Malaysia)
Contributed paper (peer-reviewed), P1h
Achieving good speech intelligibility is a central issue in a mosque. This is considering mosque is a place for prayers and particular Friday's sermon and regularly held lecture inside. Due to budgetary constrain for government project built mosques, architect normally reluctant to include typical porous material as an acoustics treatment inside. This requires new paradigm in quest of achieving optimum acoustics quality in

particular its RT60. In Malaysia, considering almost warm weather all years round, it was envisage it is possible to achieve good speech intelligibility through the use of novel acoustics material such as geometric perforated panel. The almost optimize and very minimal use of geometric perforated panel in relation to its RT60 and hence its STI are discussed in details in this paper. The STI for mosque with almost optimize geometric perforated panel indicates good speech intelligibility is achieved. However, for mosque with minimal geometric perforated panel indicates rather challenging STI. This finding suggest, this novel acoustics material in the form of geometric perforated panel can contribute to good RT60 and hence STI without any additional cost to government. This is considering this material act as part of mosque wall panel. This shall open exciting and new possibilities allowing geometric perforated panel act also as sound absorber material.

Classroom acoustics and green schools
Kenneth P. Roy (Armstrong World Industries, R&D, Lancaster, Pennsylvania, USA)
Sean D. Browne (Armstrong World Industries, R&D, Lancaster, Pennsylvania, USA)
Contributed paper (peer-reviewed), P1i
Schools are designed and built specifically for the purpose of educating students. Teachers 'teach' and students 'learn' primarily on the basis of verbal and visual cues – obviously, a primary design goal must be the acoustic performance of classrooms for speech intelligibility. Standard metrics for speech intelligibility such as Articulation Index (AI), Speech Intelligibility Index (SII), Speech Transmission Index (STI), etc. are good general indicators, but must be used carefully as they only represent speech intelligibility for young adults with both normal hearing and language recognition. Often times the key listeners in grades K-12 will be young children, 2nd language listeners, etc., such that the normal metrics do not apply. Acoustic requirements are today included in various green rating systems for schools including the United States Green Building Council (USGBC) LEED® for Schools, and the Green Building Council Australia (GBCA) Green Star – Education [5]. Acoustics are usually addressed using both the maximum acceptable room reverberation time (RT), and the maximum acceptable background noise (N). In essence, this is prescribing the speech intelligibility in terms of sound clarity and signal-to-noise (S/N) ratio. An experienced architectural designer may also wish to consider other fundamental factors such as direct-to-reflected (D/R) ratio, and sound clarity (C_{50})[6]. Sound clarity is determined by architectural design factors including classroom size, shape, and surface treatments, and it will not change unless the architecture is changed. Background noise on the other hand, is based primarily on the factors of exterior (environmental) noise intrusion, and the interior HVAC noise. The acoustic design objective for classrooms must involve designing for speech clarity with architecture, and protecting the speech clarity by ensuring good mechanical design to limit the background noise. Various classroom architectural layouts were designed and evaluated using EASE modelling software to investigate speech clarity. An actual classroom mock-up of one of these models was also investigated as a comparison to the modelling outcomes.

The relationship between sound insulation performance of walls and word intelligibility scores
Yasushi Hoshino (Environmental Acoustics Laboratory, Kobe University, Rokkodai, Nada, Kobe, Japan; Nippon Sheet Glass Environment Amenity Co,. Ltd., Takanawa, Minato, Tokyo, Japan)
Hayato Sato (Environmental Acoustics Laboratory, Kobe University, Rokkodai, Nada, Kobe, Japan)
Masayuki Morimoto (Environmental Acoustics Laboratory, Kobe University, Rokkodai, Nada, Kobe, Japan)
Yasuhiko Odagawa (Environmental Acoustics Laboratory, Kobe University, Rokkodai, Nada, Kobe, Japan)
Contributed paper (peer-reviewed), P1j
Conversation is required to be shielded from someone in an adjacent room if it includes confidential information. Word intelligibility tests were performed in a total of 185 sound fields to examine the relationship between sound insulation performance and the degree of conversation leakage. The

parameters of the test sound fields were background noise level in the next room and the sound pressure level difference between two rooms. The background noise level was changed from 30 to 50 dBA. The sound pressure level difference was parametrically changed in terms of frequency characteristics (8 kinds) and absolute values (10 kinds). The results showed that word intelligibility scores were strongly correlated with A-weighted speech-to-noise ratio and SNR_{uni32}. A multiple logistic regression analysis demonstrated that word intelligibility scores can be estimated with high accuracy from the weighted level difference and A-weighted background noise level.

Natural speech intelligibility in theatres in relation to its acoustics
Maarten P.M. Luykx (Peutz bv., Mook, Netherlands)
Martijn L.S. Vercammen (Peutz bv., Mook, Netherlands)
Contributed paper (peer-reviewed), P1k
There is a certain tendency in the design of theatres to make the halls quite large. From a perspective of natural speech intelligibility and strength of speech this is disadvantageous, because an actor's voice has a certain, limited loudness and consequently the signal-to-noise ratio at the listener may become too low. Based on the influence of signal/noise ratio on speech intelligibility, it is deduced that the strength $G \geq 6$ dB and room volumes have to be limited to 4000-4500 m^3 in order to maintain sufficient loudness for natural speech. Sound level measurements during performances with natural speech in a theatre have been performed, to determine background noise levels in the hall due to the audience and to investigate the signal-to-noise ratio of the actors voice at the audience. The background levels are mainly determined by installation noise and not by the influence of the audience.

A global index to evaluate the acoustical and thermal behavior of buildings: first evaluations and applications to common building walls in Italy
A. Magrini (Dept. of Environmental and Hydraulic Engineering, University of Pavia, Italy)
L. Cattani (Dept. of Environmental and Hydraulic Engineering, University of Pavia, Italy)
L. Magnani (Dept. of Environmental and Hydraulic Engineering, University of Pavia, Italy)
Contributed paper (peer-reviewed), P1l
In the recent years adequate thermal and acoustic comfort conditions in buildings have received more and more attention. The acoustical and thermal insulation strategies applied to building structures must be based on the correct combination of materials and building construction techniques. The aim is to guarantee comfort and good energy performance of buildings at the same time. The paper therefore proposes a study on the acoustical and thermal behavior of building structures on the basis of the calculations performed on a set of building walls, widely diffused, both in a national and international context. Thermal transmittance and apparent sound reduction index were chosen as representative parameters for thermal and acoustic characteristics definition. The paper objective is to improve the comprehension of thermal and acoustic behavior of existing building walls and to propose a new method to judge such behavior, even for new walls, based on an integrated index. For these reasons the work is divided into two parts. The first part presents a collection of walls (heavy and light kind), characterized by thermal transmittance and apparent sound reduction index values. The second part is devoted to describe a wall classification system, through an integrated index. The performance evaluation is a weighted percentage based on the improvement potential of each analyzed parameter considered. The integrated index considers also the limiting values provided by current rules or laws and technical standards. The integrated index is realized in order to offer a simple instrument to indicate the thermal and acoustic quality with just a single number (positive or negative). Such an index allows to understand immediately if the investigated walls fit, or not, design requirements.

Assessment of speech privacy in open plan offices

Joo Young Hong (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Korea)
Pyoung Jik Lee (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Korea)
Byung Kwon Lee (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Korea)
Jin Yong Jeon (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Korea)

Contributed paper, P1m

The aim of this study was to find out the most appropriate single-number quantity assessing the speech privacy and to investigate the design factors affecting the speech privacy in open plan offices. At first, field measurements were conducted in open-plan offices in order to analyze the single-number quantities listed in ISO draft 3382-3; distraction distance, rD, spatial attenuation rate of A-weighted SPL of speech per distance doubling, DL2,S, and SPL of speech at a distance of 4 meters, Lp,S,4m. Then, laboratory experiments were carried out to investigate the effects of single-number quantities on the speech privacy in open-plan offices with variation of each single-number quantity. During the listening test, the subjects were asked to evaluate the speech intelligibility and listening difficulty; contributions of each single-number quantity to speech privacy were calculated and most appropriate single-number quantity was suggested. Finally, computer simulation was performed to recommend the design guidelines for speech privacy in open plan offices.

Secret room acoustics

David Borgeaud (Environmental Resources Management, Brisbane, Australia)

Contributed paper (peer-reviewed), P1n

Most buildings require a range of acoustic privacy ratings to allow them to function adequately for the proposed uses. Selected government and private buildings have requirements for spaces where Secret and Top Secret discussions can be undertaken. These rooms have not only acoustic requirements but also other design requirements to address potential physical and electronic intrusion into these spaces. The author has worked on a number of projects incorporating Secret and Top Secret rooms with various configurations. This paper discusses acoustic and related security requirements for these rooms, and also examines the practicality of achieving the required performance via various elements of the room including the results of field testing to confirm compliance with the design intent.

Multi-channel orchestral anechoic recordings for auralizations

Michelle C. Vigeant (Architectural Engr. Prog, Univ. of Nebraska-Lincoln, Peter Kiewit Institute, 1110 S. 67th St. Omaha, NE 68182-0681, USA; Current Affiliation: Acoustics Prog., Dept. of Mech. Engr., Univ. of Hartford, 200 Bloomfield Ave, W. Hartford, CT 06117, USA)
Lily M. Wang (Architectural Engr. Prog, Univ. of Nebraska-Lincoln, Peter Kiewit Institute, 1110 S. 67th St. Omaha, NE 68182-0681, USA)
Jens Holger Rindel (Ørsted-DTU, Acoustic Technology, Technical University of Denmark, Bldg. 352, Ørsted Plads, DK-2800, Lyngby, Denmark; Current Affiliation: ODEON A/S, Scion-DTU, Diplomvej Bldg. 381, DK-2800 Kgs. Lyngby, Denmark)
Claus Lynge Christensen (Ørsted-DTU, Acoustic Technology, Technical University of Denmark, Bldg. 352, Ørsted Plads, DK-2800, Lyngby, Denmark; Current Affiliation: ODEON A/S, Scion-DTU, Diplomvej Bldg. 381, DK-2800 Kgs. Lyngby, Denmark)
Anders Christian Gade (Ørsted-DTU, Acoustic Technology, Technical University of Denmark, Bldg. 352, Ørsted Plads, DK-2800, Lyngby, Denmark; Current Affiliation: Gade & Mortensen Akustik A/S, Hans Edvard Teglers vej 5, 2. Sal, DK-2920, Charlottenlund, Denmark)

Invited paper: Special session on Recordings for Auralization, O2a

Multi-channel orchestral anechoic recordings were obtained at the Technical University of Denmark (DTU) in June 2005. Every orchestral part of specific movements of two symphonies, Brahms' Symphony No. 4, 3rd movement, and Mozart's Symphony No. 40 in g minor, 1st movement, were digitally recorded using five

0.5” DPA microphones, with four surrounding the musicians in the horizontal plane and the fifth directly above. The recordings were made in DTU’s large anechoic chamber, which has free space of about 1000 m^3 and a lower frequency limit of 50 Hz. Each musician was recorded individually, and to assist with overall synchronization of all recordings, the musicians listened to the piece over headphones and viewed a video of a conductor while playing. In general, for the string parts, two to three individual musicians were recorded, and only one instrumentalist was recorded for the remaining brass, woodwind, and percussion parts. These recordings have been edited for use in room acoustics modelling software programs to create auralizations that include some of the directional characteristics of each instrument, as individual instruments, small ensembles, or an entire orchestra.

Creating an anechoic choral recording
Ron Freiheit (Wegner Corporation, 555 Park Drive, Owatonna, MN, 55060, USA)
Invited paper (peer-reviewed): Special session on Recordings for Auralization, O2b
Auralization continues to grow as a tool for acoustical analysis and comparative listening during the planning and design phases of new construction or renovations. Expanding the library of anechoic source material to use in convolutions improves the modelling of impulse response from different architectural designs by providing demonstrations better suited to particular clients and projects. Realizing that choral anechoic source material was not readily available, the Wenger Corporation partnered with St. Olaf College and 3M to create an anechoic choral recording. The paper describes the challenges of the recording project from technological, logistical and musical standpoints and the successful solutions. A unique aspect of the project was the concurrent use of numerous microphone techniques (spaced pairs, XY, ORTF) and various microphone types. All recordings were made available in an "un-mixed" version on a DVD accompanying the CD for those who preferred an alternative to the audio recordings mixed to the CD. In total six choral arrangements were recorded in this project.

Directional database for musical instruments to be used for acoustical VR
Martin Pollow (RWTH Aachen University, Institute of Technical Acoustics)
Gottfried Behler (RWTH Aachen University, Institute of Technical Acoustics)
Invited presentation (abstract only): Special session on Recordings for Auralization, O2c
Room acoustics is commonly evaluated by measuring the room impulse responses measured with omnidirectional sound sources. Musical instruments, however, have specific radiation patterns that are part of their distinct sound characteristics. Having measured with an omnidirectional source this part of their characteristic is inevitably lost and therefore these impulse responses are not adequate for auralization of rooms with natural sound sources such as speech or music.
In order to include the directivity of musical instruments, the measurement can be done with a sound source of certain radiation pattern. An example for a flexible approach for variable directivities of technical sound sources is the twelve-channel dodecahedron loudspeaker. By applying suitable filters, the radiation pattern can be formed to match the pattern of musical instruments as closely as possible.
To evaluate the directivity of orchestral instruments, a comprehensive database was created, using anechoic recordings of clean steady tones. Hereby, the microphones were positioned to be distributed spherically around the musician to equally cover all directions of radiation. The multi-channel recording is processed to obtain a directivity function of frequency, combining the radiation of fundamentals and higher harmonics.
Now, measuring the room impulse response with the applied directivity of the instrument of interest is feasible. This is done by matching the radiation pattern of the dodecahedron loudspeaker to the specific

instrument. Basis for the 12-channel processing can be spherical harmonics and magnitude and phase optimization. Pros and cons of the methods will be discussed.

Evaluation of concert hall auralization with virtual symphony orchestra
Jukka Pätynen (Aalto University School of Science and Technology, Department of Media Technology, P.O.Box 15400, FI-00076 Aalto, Finland)
Tapio Lokki (Aalto University School of Science and Technology, Department of Media Technology, P.O.Box 15400, FI-00076 Aalto, Finland)
Invited paper (peer-reviewed): Special session on Recordings for Auralization, O2d
Authenticity of the simulation of room acoustics is evaluated by comparing auralizations with real recordings. Impulse responses are recorded in two concert halls with 34 loudspeakers positioned on the stage in the shape of an orchestra and a 3D microphone probe for spatial reproduction. The acoustics of the same concert halls are simulated with acoustics modeling software. B-format impulse responses are calculated by using the identical source and receiver positions as in the real halls. Additionally, two processing methods are applied to the simulated responses in order to decrease the difference in acoustical impression. Objective room acoustic parameters between the real and simulated halls are compared, and a listening test utilizing convolutions with anechoic orchestral music is organized. The results suggest that the subjects can be categorized in two groups having preference of brightness or naturalness. Depending on the music style, auralizations with processed responses are assessed equal or better than the real hall in terms of instrument balance and brightness.

Loudspeaker simulation of a string quartet for *in situ* listening evaluation
Timothy E. Gulsrud (Kirkegaard Associates, Boulder, Colorado, USA)
Contributed paper (peer-reviewed), P2a
A method of simulating the sound of a string quartet using an array of loudspeakers in a performance venue, with the aim of developing a repeatable sound source for in situ listening evaluation of room acoustics, is presented. In this study, a string quartet was first recorded surrounded by an array of microphones in a very dry, but not anechoic, rehearsal hall. Following the recording session, a listening jury evaluated playback of the recordings via an array of 6 loudspeakers in a small recital hall. The listening evaluation also provided an opportunity for a direct comparison between the live quartet and the simulated quartet in the performance venue. Results of the preliminary listening evaluation suggest that the loudspeaker simulation of the ensemble's sound is reasonably good, but noticeably different than the live quartet. Results also indicate that the loudspeaker array excites the room more realistically than a pair of forward facing loudspeakers. Details of the recording and playback setup, discussion of the listening evaluation results, and suggestions for improvements to the simulation are presented. Finally, the feasibility of using such recordings for auralization is discussed. The recordings are available for further research use by contacting the author at tgulsrud@kirkegaard.com.

Effect of sample size on measurement of the absorption by seats
YoungJi Choi (Department of Architectural Engineering, Jeonbuk National University, 664-14, 1Ga, Duckjin-dong, Duckjin-gu, Jeonju, Korea)
JinHak Lee (Department of Architectural Engineering, Jeonbuk National University, 664-14, 1Ga, Duckjin-dong, Duckjin-gu, Jeonju, Korea)
HyunKyung Joo (Department of Architectural Engineering, Jeonbuk National University, 664-14, 1Ga, Duckjin-dong, Duckjin-gu, Jeonju, Korea)
DaeUp Jeong (Department of Architectural Engineering, Jeonbuk National University, 664-14, 1Ga, Duckjin-dong, Duckjin-gu, Jeonju, Korea)
Contributed paper (peer-reviewed), P2b

This study deals with measurements of the sound absorption by seats which are one of the important parameters in the early design stage in auditorium. In this study, the effects of sample size on measurement of the sound absorption by seats are investigated to define an optimum range of sample size for obtaining reliable measurement results. In the measurements, the absorption coefficients of unoccupied seats at a scale of 1/16 are measured in a 1/5 scale-model of the reverberation chamber based on ISO 354. Various seating blocks having 9 different P/A (perimeter/area of the sample) values ranged from 0.4 to 1.37 m^{-1} were measured to extrapolate to the absorption coefficients of the larger seating blocks found in a real hall. The predicted results from reverberation chamber measurements were then compared to the measured values in a 1/16 scale-model of the real hall for the validation of this method. The present results show good agreement between values obtained from the hall measurements and those predicted from reverberation chamber measurements.

Study of evaluating Indoor noisiness in hospitals under temporal varieties using autocorrelation analysis
Chiung Yao Chen (Graduated School of Architecture and Urban Design, Chaoaynag University of Technology, Taiwan)
Kuo Feng Hung (Graduated School of Architecture and Urban Design, Chaoaynag University of Technology, Taiwan)
Jui Ling Chen (Architecture and Building Research Institute, Ministry of the Interior, Taiwan)
Contributed paper (peer reviewed), P2c
People in the hospital require tranquillity more than others and noise may cause greater damages to the patients. In general hospital buildings, hospitals need to maintain enormous mechanical facilities, which are the main source of noise in hospitals. Noise hazards of 16 general hospitals (single buildings) located in Taiwan were investigated in this study. As the initial stage of the investigation, the heavily trafficked hospital lobbies, including the space of the registration and dispensary counters, were chosen as the investigation objects. A 15-minute equivalent continuous noise level (Leq A) was used to display the possible noise events in the building environment plan of the hospitals. The results indicate that there is a high correlation coefficient ($r = 0.76$, $p < 0.05$) between the noise concentration rate of noise events and the scale values of being agitated by noise in lobbies as shown in the results of the noise psychology questionnaires. It worthily notes that autocorrelation analysis is applied for detecting the preferences stage of sound field as suggested by Yoichi Ando will be effective on noisiness, too.

Improving the accuracy of sound absorption measurement according to ISO 354
Martijn Vercammen (Peutz bv, Lindenlaan 41, PO Box 66, 6585 ZH, Mook, The Netherlands)
Contributed paper, P2d
Sound absorption measurements of building materials such as suspended ceilings and other products are performed in a reverberation chamber according to ISO 354. It is known that the inter laboratory reproducibility of these measurements is not very well. At this moment the differences of results between laboratories are much larger than can be accepted, e.g. from a jurisdictional viewpoint in case of building contracts and liability. Actions should be taken to reduce the spread. An ISO working group has started to investigate possibilities to improve the method. Due to the insufficient diffuse sound field in a reverberation chamber with the test sample, the shape of the reverberation room and the placing of diffusers will influence the result. A round robin research containing 13 laboratories is performed to get information on the spread and if it is possible to reduce this by correcting for the mean free path or by application of a reference material.

Estimation of reflections from impulse responses
Sakari Tervo (Aalto University, School of Science and Technology, Department of Media Technology, P.O. Box 15400, FI-00076 Aalto, Finland)
Teemu Korhonen (Tampere University of Technology, Department of Signal Processing, P.O. Box 553, FI-33101 Tampere, Finland)
Tapio Lokki (Aalto University, School of Science and Technology, Department of Media Technology, P.O. Box 15400, FI-00076 Aalto, Finland)
Invited paper (peer-reviewed), P2e
The characteristics of early reflections have a major effect on the acoustics of concert halls. In this article a framework for automatic localization of reflections and their properties is formulated. The framework uses impulse responses measured with multiple microphones. The focus is on the methods that can be used for detecting reflections and the methods that estimate the direction of arrival. Three methods for both tasks are given and their performance is measured using simulated data. Finally an example in a real auditorium is shown using the most reliable methods for detecting and estimating the direction of arrival of the reflections.

The acoustic design proposed for a church's transformation into auditoria
Lamberto Tronchin (DIENCA – CIARM, University of Bologna, Viale Risorgimento 2, Italy)
Milo Coralli (DIENCA – CIARM, University of Bologna, Viale Risorgimento 2, Italy)
Contributed paper, P2f
It is a common way in Europe to transform dismissed buildings into auditoria, especially for musical performances. In Italy there is a lack of concert halls specially designed for music, due to the historical tradition of Opera. There-fore, a strong request of concert halls requires converting more building than in foreign Countries. Among all, in Italy there are a large number of churches that cannot be used for their original purposes (i.e. messes or religious meetings) and due to economic reasons they require to be transformed into auditoria. In this paper an ancient church (which dates back to 16^{th} Century) located in Imola (30 km far from Bologna), which is planned to be converted into Audito-rium, is analyzed. The church is already utilized for musical performances but the acoustics requires to be improved. A measuring campaign was carried out by means of binaural and 3D microphones and omni-directional loudspeaker. The measurements were finalized to relate sound quality to different configuration of acoustical panels and sound source position in the stage. In the following step, an acoustic design was realized and proposed for the refurbishment of the church. The results of the measurements and of the simulation are presented.

Effects of absorption elements and stage set on the stage house acoustics in a proscenium hall
Jin You (Department of Architectural Engineerinng, Hanyang University, Seoul 133-791, Korea)
Jeong Jun Kim (Department of Architectural Engineerinng, Hanyang University, Seoul 133-791, Korea)
Jin Yong Jeon (Department of Architectural Engineerinng, Hanyang University, Seoul 133-791, Korea)
Contributed paper, P2g
Acoustical characteristics of a stage house and their effects on auditorium acoustics were investigated in a proscenium hall using computer simulation and scale models. The effects of a fly tower, the upper part of a stage house, were investigated with variable upper batten densities and covering materials. In addition, influences of the lower part of the stage house were examined by controlling the installation of absorptive finishing materials. As a result, it was found that effects of banners inside fly tower could be constant when the ratio between the banner and fly tower volume become over 13.0%. Absorptive finishing materials on the lower stage structure were also found to be influential on stage acoustics. Finally, as several types of stage sets are utilized for the lower stage structure during performances, stage sets were classified into three types, and their effects on the stage and auditorium acoustics were investigated.

Uncertainty of room acoustic measurements – How many measurement positions are necessary to describe the conditions in auditoria?

Ingo Witew (Institute of Technical Acoustics, RWTH Aachen University, Templergraben 55, D-52056 Aachen, Germany)
Pascal Dietrich (Institute of Technical Acoustics, RWTH Aachen University, Templergraben 55, D-52056 Aachen, Germany)
Diemer de Vries (Laboratory of Acoustic Imaging and Sound Control, Delft University of Technology, NL-2628 Delft, Netherlands)
Michael Vorländer (Institute of Technical Acoustics, RWTH Aachen University, Templergraben 55, D-52056 Aachen, Germany)

Contributed paper, P2h

ISO 3382 sets the framework for conducting acoustical measurements in auditoria, as this standard defines how many source-receiver combinations – depending on the room size – have to be measured in to derive general properties of the acoustic conditions. Over the years, however, it turned out that some parameters, such as Early Decay Time (EDT) or Strength (G), depend on the source-receiver distance, and hence, averaging over a number of sourcereceiver combinations will lead to a loss of information that will make proper conclusions impossible. In 1999 detailed measurements, carried out at Concertgebouw Amsterdam, showed that small changes in the microphone position are already sufficient to produce measurable fluctuations in parameters of lateral sound incidence. In other auditoria measurements have been carried out to cover entire audience areas. In this case study the tools of the "Guide to the Expression of Uncertainty in Measurements" (GUM) are used to gain new insights concerning the question of how many source-receiver combinations are necessary to describe the acoustic conditions in an auditorium. In this paper it will also be discussed to which extent singular measurements are suitable to describe the acoustical properties of entire audience areas.

Variations on acoustical measurement procedures and their influence on acoustical parameters

Fábio Leão Figueiredo (LAM - Université Pierre et Marie Curie/CNRS UMR7190/Ministère de la Culture, France)
Jean-Dominique Polack (LAM - Université Pierre et Marie Curie/CNRS UMR7190/Ministère de la Culture, France)

Contributed paper, P2i

During the year 2009, the room acoustics group of the LAM (Équipe Lutheries-Acoustique-Musique, Institut Jean Le Rond d'Alembert, Université Pierre et Marie Curie, Paris) performed a series of acoustical measurements in music halls in Paris. Variations on acoustical configurations, sound source directivities, pre-filtering signals and presence or not of public are studied. Two of the measured halls are equipped with variable acoustics, by means of sliding panels which allow modulation of the absorption surface. Measurements were made for different absorbing configurations. Besides, we used a directivity controlled sound source in some halls, which allowed changing from a directive to an omnidirectional pattern of radiation. The effects of a pre-filtering sweep signal were studied. The halls were also measured in the presence of the public. Acoustical parameters according to ISO 3382 international standard were calculated for all these variations. The results and some conclusions will be presented.

Review of objective room acoustics measures and future needs

J.S. Bradley (Institute for Research in Construction, National Research Council, 1200 Montreal Rd., Ottawa, Canada, K1A 0R6)

Invited paper (peer-reviewed): Special session on Objective and Subjective Measures, O3a

ISO 3382 describes a number of objective room acoustics parameters that are generally accepted as useful for rating some specific aspects of concert hall sound fields. They include measures of decay times, energy

ratios, measures of sound strength and several quantities related to the spatial aspects of sound fields. In most cases there are details of the measures, or their application, that raise questions. In general, there has not been a lot of practical research to explore how best to develop and use these objective measures to evaluate conditions in concert halls. For some well established measures such as Early Decay Time (EDT), we are not really sure how best to calculate their values. For other measures such as energy ratios, modifications are often proposed but without the support of subjective evaluations of the proposed changes. In other cases, such as measures of spatial impression, two approaches have been suggested, but their relative merits are not well understood. It is easy to propose ever more complex measures, but it is much more difficult to demonstrate their general utility. On the other hand, some commonly described characteristics do not have accepted related objective measures. Many more important and more general problems relate to the need, for design criteria in terms of each quantity, and for an improved understanding of just noticeable differences for each measure. This paper will discuss each measure illustrating particular problems with measurements in various halls.

New acoustical parameters and visualization techniques to analyze the spatial distribution of sound in music spaces

Alban Bassuet (Arup Acoustics, New York, USA)

Invited paper (peer-reviewed): Special session on Objective and Subjective Measures, O3b

An important factor in our appreciation of music in a hall is the perception of the spatial distribution of sound, influenced by room shape and form. This paper investigates new techniques for visualizing 3D impulse responses and two new spatial indicators are proposed: LH (ratio of low lateral versus high lateral energy), FR (ratio of front lateral versus rear lateral energy). Different room shape characteristics are illustrated from B-format measurements conducted in a selection of famous music spaces such as old and new recital and concert halls, and sacred music spaces.

Auditorium acoustics assessment with sensory evaluation methods

Tapio Lokki (Aalto University School of Science and Technology, Department of Media Technology P.O.Box 15400, FI-00076 Aalto, Finland)
Heikki Vertanen (Aalto University School of Science and Technology, Department of Media Technology P.O.Box 15400, FI-00076 Aalto, Finland)
Antti Kuusinen (Aalto University School of Science and Technology, Department of Media Technology P.O.Box 15400, FI-00076 Aalto, Finland)
Jukka Pätynen (Aalto University School of Science and Technology, Department of Media Technology P.O.Box 15400, FI-00076 Aalto, Finland)
Sakari Tervo (Aalto University School of Science and Technology, Department of Media Technology P.O.Box 15400, FI-00076 Aalto, Finland)

Invited paper (peer-reviewed): Special session on Objective and Subjective Measures, O3c

This paper reports a concert hall acoustics evaluation study which was performed with individual vocabulary profiling method. The key point in this method is that each assessor applied his individual attributes with which he rated the samples. The samples were recordings in three positions in three concert halls and parallel comparison between the samples was obtained by applying a virtual symphony orchestra, consisting of 34 loudspeakers, to excite the hall. The subjective results of 20 assessors showed that the main perceptual dimensions in this case were loudness and reverberance. In addition, clear group of attributes were formed for apparent source width, definition and distance. The applied methodology allows also the comparison of subjective results and objective room acoustic parameters. It is shown that ISO3382-1 parameters cannot explain all the variance in the subjective data.

Whole stage imaging for the control of sound strength in concert halls
Harold Marshall (Marshall Day Acoustics Pty Ltd, Melbourne, Australia)
Thomas Scelo (Marshall Day Acoustics Pty Ltd, Melbourne, Australia)
Peter Exton (Marshall Day Acoustics Pty Ltd, Melbourne, Australia)
Invited paper: Special session on Objective and Subjective Measures, O3d
The effect of early and late reflected energy upon perceived sound strength in concert halls is well known. In turn the presence of reflected energy throughout a hall may be determined by the adequacy of the design to image the stage at the frequencies of interest for any given seat or group of seats. This approach is in contrast with current ray tracing software which depends upon point to point transmission paths. Is it possible to image the whole stage in such programs are all sections of the orchestra of equal acoustical significance, and finally what design implications may be drawn? Examples from recent and historical experience address these questions.

Auditorium acoustic design: 30 years, 15 projects
Rob Harris (Arup Acoustics, Winchester, United Kingdom)
Contributed paper (peer-reviewed), P3a
The acoustic design practice Arup Acoustics celebrated its 30th anniversary in 2010. This paper reviews 15 of the auditoria projects acoustically designed by Arup over this period. Specific acoustic design considerations are discussed for the projects and the projects are used to track the development of auditorium acoustic design over the last 30 years. Equally, recent new challenges to acoustic designers are identified, as are aspects of auditorium acoustic design which have not developed sufficiently over the study period.

The reconstruction of the Teatro Galli in Rimini: the acoustic design
Lamberto Tronchin (DIENCA – CIARM, University of Bologna, Viale Risorgimento 2, Italy)
Contributed paper, P3b
The town of Rimini, Northern Italy, was founded in 268 BC, in an area that had previously been inhabited by the Etruscans, the Umbrians, the Greeks and the Gauls. The Romans called this colony Ariminum, probably from the name of a nearby river, Ariminus (today, Marecchia). It was seen as a bastion against invading Gaul and also as a springboard for conquering the Padana plain. Rimini was a road junction connecting central Italy (Via Flaminia) and northern Italy (Via Aemilia that led to Piacenza and Via Popilia) and it also opened up trade by sea and river. Rimini drew the attention of many Roman emperors, including Augustus who did much for the city and Hadrian in particular. This great period in its history was embodied by the construction of prestigious monuments such as the Arch of Augustus, Tiberius' Bridge and the Amphitheatre and Galla Placida built the church of San Stefano. During the 19th Century the town acquired an international reputation for the seaside, and a new theatre which was designed by Luigi Poletti succeeded in translating into Neoclassical form the ambitions of the ruling classes. The theatre was completely destroyed during II World War. In the following decades, many proposals were developed for the new theatre. In 2003, the final design was accepted, following the rule “where it was, how it was”. In this paper the new design is analyzed, and the results from the simulations are evaluated and compared with other similar theatres.

Room acoustics investigations in Hamer Hall at the Arts Centre, Melbourne
Timothy Gulsrud (Kirkegaard Associates, Boulder, Colorado USA)
Peter Exton (Marshall Day Acoustics, Melbourne, Australia)
Arthur van der Harten (Kirkegaard Associates, Chicago, Illinois USA)
Larry Kirkegaard (Kirkegaard Associates, Chicago, Illinois USA)
Contributed paper (peer-reviewed), P3c

This 2,380 seat performance venue within Melbourne's Arts Centre is scheduled for upgrades to its interiors and acoustics as part of the Southbank Cultural Precinct Redevelopment. Kirkegaard Associates and Marshall Day Acoustics have made collaborative room acoustics investigations in the hall to advice on the acoustic improvements. This paper outlines the listening and measurement investigations in the hall and reports some of the significant results found during the investigations. Comparisons between measurements made with a small directional loudspeaker supplemented with a subwoofer to a standard dodecahedral loudspeaker are presented. Occupied reverberation times measured in the hall, which to our knowledge have not been previously published, are also presented. Variation of measured Early Decay Time is described. The reflected sound from side wall diffusion elements has been analysed and is discussed with reference to boundary element method (BEM) model results.

Acoustical considerations in the design of Heydar Aliyev Center Auditorium
Zuhre Su Gul (Department of Architecture, Middle East Technical University, Ankara, Turkey; MEZZO Studio Ltd. Ankara, Turkey)
Mehmet Caliskan (Department of Mechanical Engineering, Middle East Technical University, Ankara, Turkey)
Contributed paper (peer-reviewed), P3d
The auditorium within the Heydar Aliyev Center serves for an audience of 1200 and incorporates conference, concert and opera use altogether. Confronting the multi-functional performance program of the space together with uncompromising aesthetic considerations, coupled space concept has been adopted as an acoustical and architectural design aid. This paper presents mainly the dependable acoustics attained by the coupling of auxiliary spaces by employing of the right-sized coupled volume connected with proper finishing materials and variable aperture size which consequences in the differentiation of reverberation time within the main volume -namely multi-purpose auditorium- and the coupled room. Fixing the volume and room finishes as for getting the desired energy decay behavior, aperture size has come up to be the essential parameter to concentrate on. The proposed solution for conference, music and inter-related activities is for the best of early and late sound field energy decay control. The proper reverberation times are studied for the main hall alone and coupled space separately to find the results as of the optimum reverberation times over frequency range of the auditorium for performance-specific. Aperture size has an essential role in balancing the reverberation time distributions of the auditorium and coupled space. Stage tower acoustics and thoroughly wooden surfaces of auditorium are studied together with the coupled volume in search of optimum reverberation times for different purposes of coupling spaces. Within this study coupled volume is used as a design tool out of recent acoustical innovations. The form and materials within the main volume is worked out together to get the optimum sound energy decay forms for different activities. Apart from coupled space concept, stage house design, auditorium main back-wall design and side-wall face irregularities are studied within the aim of having an even distribution of sound field throughout the hall. This paper presents the successful outcomes of a coupled volume design within such a collection of irregular forms out of minimum aesthetic compromises.

Acoustical design of new Danish Radio concert hall
Motoo Komoda (Nagata Acoustics America, Inc, 2130 Sawtelle Blvd Suite 308 Los Angeles CA 90025, U.S.A.)
Ayako Hakozaki (Nagata Acoustics, Inc, 2-35-10-3F Hongo Bunkyo-ku Tokyo 113-0033, Japan)
Yasuhisa Toyota (Nagata Acoustics America, Inc, 2130 Sawtelle Blvd Suite 308 Los Angeles CA 90025, U.S.A.)
Contributed paper (peer-reviewed), P3e
A new 1800-seat concert hall at the Danish Radio complex in Copenhagen opened in January 2009. The new hall primarily serves classical music forms such as orchestra, chamber ensemble, solo recital, etc. The

seating layout of the hall is based upon the vineyard style. During all design phases, the room shape was studied with computer simulations and near the completion of design a detrimental echo check was performed using a 1:10 scale model. Presented here is the acoustical design of the new hall, as well as acoustical data measured after completion.

A mid-size concert hall with staggered terraced seating

Wei-hwa Chiang (National Taiwan University of Science and Technology 43, Keelung Rd. Section 4, Taipei 106, Taiwan, R.O.C.)
Wei Lin (Hwa-Hsia Institute of Technology, 111 Gong Jhuan Rd., Chung Ho, Taipei, Taiwan, R.O.C.)
I-te Yeh (National Taiwan University of Science and Technology 43, Keelung Rd. Section 4, Taipei 106, Taiwan, R.O.C.)
Yen-kun Hsu (National Taiwan University of Science and Technology 43, Keelung Rd. Section 4, Taipei 106, Taiwan, R.O.C.)

Contributed paper, P3f

The new Pingtung Performing Arts Center at Southern Taiwan features a mid-size concert hall. The significant portion of seats surrounding the stage and the extra width makes it possible to use terraced seating layout. The terraces were staggered to correspond to the asymmetry of the building and to amplify the size of the reflective surfaces bounding the terraces. Inclined surfaces were also appeared on upper walls where distances between walls were shortened to provide higher order early reflections. Computer simulation was performed to adjust the angle of these diffusive and inclined surfaces to simultaneously satisfy clarity, strength, sectional balance, and stage support. The surfaces near the stage were in particular tuned to direct reflections not only to the nearby audiences at the lowest level but also to the performers and the audiences surrounding the stage.

Acoustical renovation of large auditorium to enhance sound strength and IACC

Hyo Joo Yoo (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Chun Ki Seo (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Jae Ho Kim (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Jin Yong Jeon (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)

Contributed paper, P3g

The Grand Theater in the Sejong Performing Arts Center is a proscenium theater with 3,022 seats. Originally built in 1978, the first renovation was conducted in 2004 to provide variable reverberation time (RT) using a sound system. Recently, a renovation was again planned to enhance the acoustic quality, especially sound strength (G) and spatial responsiveness (IACC), based on architectural acoustic design. The orchestra shell and various ceiling/wall reflectors were redesigned to improve the acoustic quality in calculation of G and IACC. The side balconies were added to pro-vide lateral reflections to the audience sitting in the stalls. Materials of the walls and chairs were changed for longer RT and higher G. In this paper, the results of a computer simulation as well as the acoustical design process were presented.

The effect of reflectors on sound strength (G) and IACC in a fan-shape hall

Jae Ho Kim (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Chun Ki Seo (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Hyo Joo Yoo (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Jin Yong Jeon (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)

Contributed paper, P3h

The effects of various reflecting surfaces on the audience G and IACC were investigated by using open-type 1:10 scale model. In this study, the orchestra shell and three types of reflector were designed to increase the G_{mid} and 1-$IACC_{E3}$. The reflectors were composed of triangular panels; the area of basic module was designed as 9 m^2, based on the previous study [Nakajima et al., J. Acoust. Soc. Am. 92, 1443–1451 (1992)]. In addition, the shape of reflectors was optimized by genetic algorithm to increase G and 1-IACC. Measurements of open-type 1:10 scale model were conducted to investigate the effect of reflectors on early sounds in the auditorium. The results indicated that G and IACC were changed around 5.8 dB and 0.29, respectively, when all the reflectors were installed.

The case for widely variable acoustics

Steve Ellison (Meyer Sound Labs, Berkeley, CA, USA)
Roger Schwenke (Meyer Sound Labs, Berkeley, CA, USA)

Contributed paper, P3i

High real estate, construction, and maintenance costs frequently preclude the creation of single purpose facilities for musical performance. Multi-purpose facilities are conceived that typically present a nominal acoustic suited to the most common use. However, this may be too reverberant for spoken word and not reverberant enough for choral music. To address this, active acoustics can be employed to provide a wide range of reverberation time change. As a result, orchestras are now performing in contemporary churches and choirs are sharing the stage with theater companies. How are these musical forms being served? A survey of preferred acoustical ranges will be presented for speech, reproduced sound, reinforced music, and acoustic music genres. Examples of venues that utilize active acoustics to widen their performance palette will include a worship space, performing art center, and experimental music studio. Their acoustic performance will be compared with archetypal acoustic music venues. The potential for new types of performances that are enabled by active acoustics will be discussed.

The acoustical design of the new national opera house of Greece

Alban Bassuet (Arup Acoustics, New York, USA)

Contributed paper (peer-reviewed): General Chair's Selected Papers in Auditorium Design, O4a

Scheduled to open in 2015 in the city of Athens the Stavros Niarchos Foundation Cultural Center will become the new home for the Greek National Opera and Ballet. This paper presents the acoustical design considerations for the future opera theatre. A retrospective of Greek influence in the history of the opera theatre design is presented with benchmarking and precedents considered for the project. Through presentations of the some of the design thoughts and approaches still in development, including the form, geometry, seating distribution, wall shaping, and materials in the opera theatre, the paper describes how the new design references and incorporates the profound influence of Greek Culture on development of the Opera House as we know it today.

The acoustical design of the new Yamaha Hall

Hideo Miyazaki (Sound & IT Development Division, Yamaha Corp., 203 Matsunokijima Iwata, Shizuoka 438-0192, Japan)
Shinjiro Yamashita (Sound & IT Development Division, Yamaha Corp., 203 Matsunokijima Iwata, Shizuoka 438-0192, Japan)
Yasushi Shimizu (Sound & IT Development Division, Yamaha Corp., 203 Matsunokijima Iwata, Shizuoka 438-0192, Japan)
Yoshihide Shiba (Nikken Sekkei Ltd., 2-18-3 Iidabashi, Chiyoda-ku Tokyo 102-8117, Japan)
Ami Tanaka (Nikken Sekkei Ltd., 2-18-3 Iidabashi, Chiyoda-ku Tokyo 102-8117, Japan)

Contributed paper (peer-reviewed) : General Chair's Selected Papers in Auditorium Design, O4b

The Yamaha Ginza Building, which opened about 60 years ago, was renewed as a commercial complex that has four types of facilities: shops, music instruction rooms, hall facilities, and an information center. The new Yamaha Hall, located on the seventh to ninth floors, has been designed under the concept of a concert hall that has attractive and unique acoustics that are optimal for acoustical instruments and can never be experienced in other spaces. To control the ASW of a small room, where strong reflections from side walls often cause ambiguous sound images, scale model experiments and subjective tests using an auralization system based on a computer simulation have been used to study the pattern of the side walls. In addition, Yamaha's original wood enhancement technologies, which have been gained through the development of materials for musical instruments and utilized for violins, acoustic guitars, etc., have been implemented in the stage floor to achieve the mature, warm sound of the hall.

Equal reverberance contours for synthetic room impulse responses listened to directly: Evaluation of reverberance in terms of loudness decay parameters

Doheon Lee (Faculty of Architecture, Design and Planning, University of Sydney, NSW 2006, Australia)
Densil Cabrera (Faculty of Architecture, Design and Planning, University of Sydney, NSW 2006, Australia)
William L. Martens (Faculty of Architecture, Design and Planning, University of Sydney, NSW 2006, Australia)

Contributed paper (peer-reviewed), P4a

This paper examines effects of listening level and reverberation time on the perceived decay rate of synthetic room impulse responses (RIRs). A listening test was conducted with synthetic RIRs having a range of listening levels and reverberation times: in the test, subjects adjusted a physical decay rate of the RIRs to match the perceived decay rate of reference stimuli. In this way, we constructed equal reverberance contours as a function of sound pressure level and reverberation time. The experiment results confirm that listening level and reverberation time both significantly affect reverberance. The study also supports our previous findings: that the loudness decay function in can be used to predict reverberance better than the conventional reverberance predictors.

An artificial listener for assessing content-specific objective parameters related to room acoustical quality

Jasper van Dorp Schuitman (Delft University of Technology, Faculty of Applied Sciences, Laboratory of Acoustical Imaging and Sound Control, Lorentzweg 1, 2628 CJ Delft, The Netherlands)
Diemer de Vries (Delft University of Technology, Faculty of Applied Sciences, Laboratory of Acoustical Imaging and Sound Control, Lorentzweg 1, 2628 CJ Delft, The Netherlands)

Contributed paper (peer-reviewed), P4b

A nonlinear, binaural auditory model was developed which is able to act as an artificial listener for assessing features related to the quality of room acoustics. The model is able to derive objective parameters for reverberance, clarity, apparent source width (ASW) and listener envelopment (LEV). In order to derive these parameters, the model splits the input audio into two streams: one related to the source (direct sound) and one related to the environment (room). In order to derive these two streams, the splitting

algorithm makes use of the nonlinear properties of the auditory model. The whole algorithm works on arbitrary binaural recordings and therefore the parameters can for example be determined in a concert situation using an artificial head. This way the signal type is automatically taken into account, meaning that the acoustics of a room can be tested for multiple types of stimuli. Listening tests show that the resulting objective parameters correlate highly with perceptual results, even in cases where conventional objective parameters show low correlation coefficients.

A quasi-binaural approach to head-movement-aware evaluation of spatial acoustics
Chungeun Kim (Institute of Sound Recording, University of Surrey, Guildford, GU2 7XH United Kingdom)
Russell Mason (Institute of Sound Recording, University of Surrey, Guildford, GU2 7XH United Kingdom)
Tim Brookes (Institute of Sound Recording, University of Surrey, Guildford, GU2 7XH United Kingdom)
Contributed paper (peer-reviewed), P4c
This research incorporates the nature of head movement made in listening activities, into the development of a quasi-binaural acoustical measurement technique for the evaluation of spatial impression. A listening test was conducted where head movements were tracked whilst the subjects rated the perceived source width, envelopment, source direction and timbre of a number of stimuli. It was found that the extent of head movements was larger when evaluating source width and envelopment than when evaluating source direction and timbre. It was also found that the locus of ear positions corresponding to these head movements formed a bounded sloped path, higher towards the rear and lower towards the front. This led to the concept of a signal capture device comprising a torso-mounted sphere with multiple microphones. A prototype was constructed and used to measure three binaural parameters related to perceived spatial impression - interaural time and level differences (ITD and ILD) and interaural cross-correlation coefficient (IACC). Comparison of the prototype measurements to those made with a rotating Head and Torso Simulator (HATS) showed that the prototype could be perceptually accurate for the prediction of source direction using ITD and ILD, and for the prediction of perceived spatial impression using IACC. Further investigation into parameter derivation and interpolation methods indicated that 21 pairs of discretely spaced microphones were sufficient to measure the three binaural parameters across the sloped range of ear positions identified in the listening test.

Investigation of the correlation between late lateral sound level and total acoustic absorption, and an overview of a related subjective study
Michelle C. Vigeant (Acoustics Prog. and Lab., Dept. of Mech. Engr., Univ. of Hartford, 200 Bloomfield Ave, W. Hartford, CT 06117, USA)
Robert D. Celmer (Acoustics Prog. and Lab., Dept. of Mech. Engr., Univ. of Hartford, 200 Bloomfield Ave, W. Hartford, CT 06117, USA)
David A. Dick (Acoustics Prog. and Lab., Dept. of Mech. Engr., Univ. of Hartford, 200 Bloomfield Ave, W. Hartford, CT 06117, USA)
Contributed paper, P4d
Listener envelopment (LEV), the sense of being immersed in a sound field, can be quantified in terms of Bradley and Soulodre's parameter called late lateral sound level (GLL) (1995). Room acoustics parameters, including GLL, were measured in a 900-seat theatre with variable acoustics in five receiver locations in three hall settings, with the mid-frequency reverberation time ranging between 1.35 to 1.59 s. The overall range of measured GLL values, across all receivers and configurations, was between 16.1 to 20.4 dB. Binaural recordings were also obtained for most receiver and hall setting combinations. A detailed model of the space was created in ODEON v9.20 and validated using the measured reverberation time, early decay time, and clarity index values within less than 2 just-noticeable-differences. Barron's theory, that GLL is related to total acoustic absorption in a hall (2001) was tested using the measured GLL values and the

estimated total acoustic absorption values from the validated model. A significant correlation was found for the upper octave bands only. A listening test was also conducted using the binaural recordings to determine the correlation of the subjective LEV ratings of these recordings with the measured GLL values. The subjects rated LEV on a scale from 1 to 5, and a significant linear correlation was found between the LEV ratings and the measured GLL values.

Application of auditory filter for evaluation of sound and sound field
Yuki Matsumoto (Faculty of Design, Kyushu University, Fukuoka 815-8540, Japan)
Masahiro Suzuki (Faculty of Design, Kyushu University, Fukuoka 815-8540, Japan)
Hisako Ogushi (Faculty of Design, Kyushu University, Fukuoka 815-8540, Japan)
Akira Omoto (Faculty of Design, Kyushu University, Fukuoka 815-8540, Japan)
Contributed paper (peer-reviewed), P4e
Auditory filters that simulate function of the human auditory organ are introduced for the evaluation of a sound and sound field. Three applications are discussed in this report. The first examines the similarity of sound fields. Music signals convolved with different impulse responses are compared subjectively and quantitatively. The output of the auditory filter indicated high correlations with subjective evaluation. The second example examines the decay process of the sound field, especially in rather dead conditions. Impulse responses measured in recording studios are passed through both an auditory filter and a conventional band-pass filter. Decay processes are then calculated by inverse integration. The responses after passing through the auditory filter show more stable decay curves and the obtained reverberation times are closer to the early decay time, which is closely related to human perceived reverberance. The timbres of musical instruments are used as the third example. The signals from instruments with different means of sound production (such as reed or mouthpiece) are processed by auditory filters and normal band-pass filters. Statistically-obtained characteristics such as kurtosis of the waveform again show higher correlation with subjective evaluation when employing the auditory filter. All the results shown in this report strongly suggest the superiority of an auditory filter in the qualitative evaluation of sounds and sound fields.

Perception of scattered sounds in rectangular concert halls
Yong Hee Kim (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Hyo Joo Yoo (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Jin Yong Jeon (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Contributed paper, P4f
This paper investigates objective and subjective responses on scattered sounds from rectangular concert halls. A concert hall with 450-seats and highly diffusive lateral walls was measured based on ISO 3382-1. Acoustical parameters such as RT, EDT, G, C80, LF and IACC were used for objective evaluation of scattered sounds. The impulse responses of the concert hall were selected according to the measurement results of "Number of peaks" for *in situ* diffusivity evaluation. Auditory experiments were performed with 8 auralized music sounds with normalized impulse responses. The effective diffusion parameter was discussed through the subjective test results.

Considerations in characterising an almost anechoic room for interactive spatial audio reproduction
Densil Cabrera (Faculty of Architecture, Design and Planning, The University of Sydney, NSW 2006, Australia)
Takuma Okamoto (Research Institute of Electrical Communication, Tohoku University, 2-1-1, Katahira, Aoba-ku, Sendai, 980-8577, Japan)
Brian F.G. Katz (LIMSI-CNRS, BP 133, 91403, Orsay, Cedex, France)
Markus Noisternig (IRCAM-CNRS UMR STMS, 1, Place Igor-Stravinsky, 75004, Paris, France)
Yukio Iwaya (Research Institute of Electrical Communication, Tohoku University, 2-1-1, Katahira, Aoba-ku, Sendai, 980-8577, Japan)
Yo-iti Suzuki (Research Institute of Electrical Communication, Tohoku University, 2-1-1, Katahira, Aoba-ku, Sendai, 980-8577, Japan)
Contributed paper (peer-reviewed), P4g
Rooms for soundfield reproduction, such as for higher order Ambisonics, should be anechoic but also require many loudspeakers. Other practical considerations, such as a weight-bearing floor, mechanical services, and available room volume may limit the anechoic performance of such rooms. One way to characterise the performance of such rooms combined with their audio system is to measure the response from each loudspeaker to the listening area (or sweet spot). However, we consider the case of a room for interactive spatial audio reproduction, where a talking person's voice is reproduced in the virtual environment for that person to hear and interact with in real-time. We consider the practicality of various characterisation techniques, such as reverberation time, sound strength and deviation from the inverse-square law, for a small room containing 157 loudspeakers before and after sound absorptive treatment.

Virtual reality system at RWTH Aachen University
Dirk Schröder (Institute of Technical Acoustics, RWTH Aachen University, Aachen, Germany)
Frank Wefers (Institute of Technical Acoustics, RWTH Aachen University, Aachen, Germany)
Sönke Pelzer (Institute of Technical Acoustics, RWTH Aachen University, Aachen, Germany)
Dominik Rausch (Virtual Reality Group, RWTH Aachen University, Aachen, Germany)
Michael Vorländer (Institute of Technical Acoustics, RWTH Aachen University, Aachen, Germany)
Torsten Kuhlen (Virtual Reality Group, RWTH Aachen University, Aachen, Germany)
Contributed paper (peer-reviewed), P4h
During the last decade, Virtual Reality (VR) systems have progressed from primary laboratory experiments into serious and valuable tools. Thereby, the amount of useful applications has grown in a large scale, covering conventional use, e.g., in science, design, medicine and engineering, as well as more visionary applications such as creating virtual spaces that aim to act real. However, the high capabilities of today's virtual reality systems are mostly limited to first class visual rendering, which directly disqualifies them for immersive applications. For general application, though, VR-systems should feature more than one modality in order to boost its range of applications. The CAVE-like immersive environment that is run at RWTH Aachen University comprises state-of-the-art visualization and auralization with almost no constraints on user interaction. In this article a summary of the concept, the features and the performance of our VR-system is given. The system features a 3D sketching interface that allows controlling the application in a very natural way by simple gestures. The sound rendering engine relies on present-day knowledge of Virtual Acoustics and enables a physically accurate simulation of sound propagation in complex environments, including important wave effects such as sound scattering, airborne sound insulation between rooms and sound diffraction. In spite of this realistic sound field rendering, not only spatially distributed and freely movable sound sources and receivers are supported, but also modifications and manipulations of the environment itself. The auralization concept is founded on pure FIR filtering which is realized by highly parallelized non-uniformly partitioned convolutions. A dynamic crosstalk cancellation system performs the sound reproduction that delivers binaural signals to the user without the need of

headphones. The significant computational complexity is handled by distributed computation on PC clusters that drive the simulation in real-time even for huge audio-visual scenarios.

Active acoustic systems for the control of room acoustics
Mark A. Poletti (Industrial Research Limited, Lower Hutt, New Zealand)
Keynote address (peer-reviewed), K2
The acoustic design of auditoria involves the specification of the room geometry and boundary properties, and any additional acoustic elements such as reflectors or diffusers, to usefully direct sound to produce a desired subjective experience, quantified by measurable acoustic parameters. This design must take into account the reflection of sound within the stage area, the early reflections from the stage to the audience and the reverberant response of the room. The sound produced by the audience can also be an important consideration. Active acoustic systems provide an alternative approach to controlling subjective experience. They use microphones, electronic processors and loudspeakers to create reflections and reverberation in addition to those produced by the naturally-occurring sound field. The acoustic properties can be changed instantly, and the enhanced acoustic properties of the auditorium can typically be varied over a wider range than can be produced by variable passive techniques. The design of active acoustics follows that of passive approaches, but rather than the physical arrangement of the room surfaces, it commences with an existing passive space with some minimum acoustic condition, and requires the arrangement of microphones to detect relevant sound and the choice of processors and loudspeaker positions to direct it usefully back into the room to produce a desired set of acoustic parameters. While active systems have historically been developed with the goal of enhancing either the stage or audience sound, they must generally provide the same control of sound as passive acoustic design. This paper discusses the principles of active acoustic systems and how they are used to achieve the required range of control. A survey of current commercial systems is given and some implications for the future of live performance are explored.

Improvement of the acoustics under the balcony in auditoria using the electro-acoustic method - A study with a full-scale model
Takayuki Watanabe (Spatial Audio Research Group, Sound & IT Development Division, Yamaha Corp., 203 Matsunokijima Iwata, Shizuoka 438-0192, Japan)
Masahiro Ikeda (Spatial Audio Research Group, Sound & IT Development Division, Yamaha Corp., 203 Matsunokijima Iwata, Shizuoka 438-0192, Japan)
Contributed paper (peer-reviewed), P5a
In auditoria, the acoustical properties of audience areas located under balconies are regarded as inferior to the main area. This is caused by the reduction of direct and reflected sound energy due to the smaller open area and the reduction of diffusive energy due to the limited acoustical space. In this paper, a new electro-acoustic system is proposed to compensate for this acoustical condition. The proposed system is a non-regenerative system and consists of directional microphones, head amps, a convolver, a matrix processor, amplifiers, and ceiling loudspeakers located under the balcony. The loudspeakers, located at positions corresponding to measurement points across the balcony, recreate the reflecting sound from above the balcony area, which otherwise fail to reach to the listeners under the balcony. The authors have examined the proposed system's performance via two methods: acoustical measurement using a full-scale model and a corresponding psycho-acoustical experiment. The results showed that the energy of the reflections from above the system was the same or more than that without the balcony, and the decay curve with the system was almost the same as that without the balcony. The MUSHRA method was used in the psycho-acoustical experiment, which focused on the evaluation of apparent source width (ASW) and listener envelopment (LEV). The results of the experiment show that the system is significantly better for all tests to the use of no system and that the system is superior to a standard PA (delay system).

Soundfield synthesis with spatio-temporal compensation
Deep Sen (School of EE&T, University of New South Wales, Sydney, Australia)
Shuai Wang (School of EE&T, University of New South Wales, Sydney, Australia)
Qingqing Meng (School of EE&T, University of New South Wales, Sydney, Australia)
Contributed paper (peer-reviewed), P5b
Practical soundfield synthesis systems are required to recreate the original soundfield at a multitude of diverse arbitrary acoustic environments. For accurate reconstruction, it is essential that the local acoustic characteristics are equalized at the playback venue. This requires physical measurement and monitoring of the local spatio-temporal characteristics. In this paper, we present an implementation for spherical harmonic based soundfield synthesis systems which uses previously published methods for measuring the local spatio-temporal response. The multipoint measurement uses an amplitude modulated log-swept stimuli which is subsequently incorporated as time domain inverse filters into the spherical-harmonic based synthesis framework. The time-domain inversion of the impulse responses are non-trivial in practice due to their mixed-phase characteristics. The complete methodology accounts for the spatio-temporal response of each loudspeaker (for arbitrary loudspeakers and playback environments) as well as local room acoustics. The recreated soundfield is evaluated by asking a pool of listeners to perform Ref/A-B tests. The reference stimulus is a binaural recording of the same soundfield using a B&K Head and Torso Simulator. The stimuli were presented to the listeners using headphones. The A & B candidates are the equalized and non-equalized soundfield synthesized using 25 loudspeakers in a non-anechoic environment.

Application of analytic sweep segments in room acoustic measurements
Csaba Huszty (Graduate School, The University of Tokyo, Ce 401 4-6-1 Komaba, Meguro-ku, Tokyo, 153-8505, Japan)
Sakae Yokoyama (Institute of Industrial Science, The University of Tokyo, Ce 401 4-6-1 Komaba, Meguro-ku, Tokyo, 153-8505, Japan)
Shinichi Sakamoto (Institute of Industrial Science, The University of Tokyo, Ce 401 4-6-1 Komaba, Meguro-ku, Tokyo, 153-8505, Japan)
Contributed paper (peer-reviewed), P5c
Room acoustic measurements employing indirect signals to obtain room impulse responses are widely used nowadays, particularly swept sine signals. In this paper, application of a general method creating excitation signals solely in time-domain with sigmoid, monomial power function and generalized exponential modulation functions are presented. By using such signals it is possible to match different optimization criteria such as customizing the SNR frequency function of the resulting room impulse response and obtain useful results in a wider frequency region where excitation signal is present. Theoretical and practical aspects are presented with measurement results and total harmonic distortion (THD) response analysis.

Room acoustics simulation for multichannel microphone arrays
Andrew Wabnitz (Computing and Audio Research Laboratory (CARLab), School of Electrical and Information Engineering, The University of Sydney, NSW, Australia)
Nicolas Epain (Computing and Audio Research Laboratory (CARLab), School of Electrical and Information Engineering, The University of Sydney, NSW, Australia)
Craig Jin (Computing and Audio Research Laboratory (CARLab), School of Electrical and Information Engineering, The University of Sydney, NSW, Australia)
André van Schaik (Computing and Audio Research Laboratory (CARLab), School of Electrical and Information Engineering, The University of Sydney, NSW, Australia)
Contributed paper (peer-reviewed), P5d
A new and efficient room acoustics simulation software package for MATLAB is presented which can simulate recordings of arbitrary microphone arrays within an echoic room. This simulator supports research related to developing and experimenting with multichannel microphone arrays and higher order ambisonic

playback. Based upon the work by Schimmel et al., this new simulation software package models both specular and diffuse reflections in a shoebox type environment. It is an improvement over previous work as it can simulate microphone arrays with arbitrary directional impulse responses and large numbers of sensors. The spherical harmonic expansion up to a specified order at any point within an echoic room can also be simulated by specifying a microphone array with custom directional gains that match the spherical harmonic functions. Furthermore, this simulator provides realistic phase information for the sound recorded by the microphone array, including accurate inter-sensor time delays for the sources and early specular reflections. The room acoustics simulator is implemented as a C program that interfaces with MATLAB and is freely available from the authors.

Objective assessment of active acoustic system performance
Roger Schwenke (Meyer Sound Laboratories, 2832 San Pablo Ave, Berkeley, CA, USA)
Steve Ellison (Meyer Sound Laboratories, 2832 San Pablo Ave, Berkeley, CA, USA)
Contributed paper, P5e
The reverberation of a room may be controlled passively by changing the amount of absorption, or changing the cubic volume, thereby controlling the rate at which sound is subtracted from a room. A room can be controlled actively using microphone, signal processing, and speakers to control the rate at which sound is added back into a room. Active Acoustic systems can decrease the effective absorption of a space by increasing the gain between system microphones and speakers. They can affect the apparent volume of the space by adding electronic reverberation between the microphones and speakers. The range of possible change in apparent absorption and cubic volume will be predicted and measured. Examples will be given showing that the resulting warmth, clarity, and early decay time can be controlled independently from the late reverberation time, and that strength and binaural quality can be improved. It will be shown that a room with active acoustics needs half the cubic volume of an equivalent room using passive acoustics, contributing (along with other factors) to the environmental sustainability of a building as represented by LEED points.

Identification of admittance parameters in arbitrarily shaped interiors based on sound pressure measurements using a 3d-FEM-based inverse algorithm
Robert Anderssohn (Institute of Solid Mechanics, Technische Universitaet Dresden, Dresden, Germany)
Steffen Marburg (Institute of Mechanics, Universitaet der Bundeswehr Muenchen, Munich, Germany)
Hans-Juergen Hardtke (Institute of Solid Mechanics, Technische Universitaet Dresden, Dresden, Germany)
Contributed paper, P5f
Knowledge about the dynamics of walls surrounding arbitrarily shaped spaces is important to determine, predict and optimize the acoustics within. The dynamics may be quantified in terms of the acoustical boundary impedance or boundary admittance, respectively. The authors aim to approximate a discrete distribution of admittance values for the entire boundary. An inverse, FEM-based algorithm shall utilize sound pressure data obtained from a set of microphone placements to estimate those system parameters. The algorithm requires phase related knowledge of the excitation through sound sources and structural vibration on the boundary. Computationally, it leads to a generally ill-conditioned, non-linear least-squares problem whose operation depends mainly on the relation of the numbers of unknowns and microphones, their locations and noise. Results obtained on three-dimensional numerical models will be discussed.

The effect of an edge on the measured scattering coefficients in a reverberation chamber based on ISO17497-1

JungSu Kim (Department of Architectural Engineering, Jeonbuk National University, 664-14, 1Ga, Duckjin-dong, Duckjin-gu, Jeonju, Korea)
JinHak Lee (Department of Architectural Engineering, Jeonbuk National University, 664-14, 1Ga, Duckjin-dong, Duckjin-gu, Jeonju, Korea)
YoungJi Choi (Department of Architectural Engineering, Jeonbuk National University, 664-14, 1Ga, Duckjin-dong, Duckjin-gu, Jeonju, Korea)
DaeUp Jeong (Department of Architectural Engineering, Jeonbuk National University, 664-14, 1Ga, Duckjin-dong, Duckjin-gu, Jeonju, Korea)

Contributed paper (peer-reviewed), P5g

The scattering coefficient has been regarded as one of the important factors to be considered in the acoustic design of a room. ISO 17497-1 provides a method for measuring the random-incidence scattering coefficients in a reverberation chamber. However, the uncertainties of this method due to the lack of details with respect to the measurement conditions have been reported. It is necessary to provide more specific guidelines for this method. The present study suggests an improved measurement method by investigating the edge effects. The scattering coefficients of a simple 1-dimensional diffuser were measured in a 1/5 scale model of the reverberation chamber based on ISO 17497-1. The effects of an edge stripe on the scattering coefficients were measured and analysed. Further, several issues with respect to the sample diameter, the air gap below the turntable and the absorption of the test sample were discussed.

Room acoustics modeling with acoustic radiance transfer

Samuel Siltanen (Aalto University School of Science and Technology, Department of Media Technology P.O.Box 15400, FI-00076 Aalto, Finland)
Tapio Lokki (Aalto University School of Science and Technology, Department of Media Technology P.O. Box 15400, FI-00076 Aalto, Finland)
Lauri Savioja (Aalto University School of Science and Technology, Department of Media Technology P.O. Box 15400, FI-00076 Aalto, Finland)

Invited paper (peer-reviewed), P5h

Acoustic radiance transfer is a surface-element-based computational room acoustics modeling method. It is based on the room acoustic rendering equation, and it enables modeling of arbitrary reflection functions. In this paper, we review both the time-domain and frequency-domain formulations of the technique. As acoustic radiance transfer is based on geometrical acoustics it lacks diffraction modeling, but there are several ways to incorporate diffraction into it, as discussed. The main novelty of this work is the use of non-uniform sampling in response representation allowing the method to invest more samples to high energy parts of the response thus optimizing resource allocation. The proposed hybrid modeling brings further benefits by combining the advantages of the beam tracing and acoustic radiance transfer methods.

Rays or waves? Understanding the strengths and weaknesses of computational room acoustics modeling techniques

Samuel Siltanen (Aalto University School of Science and Technology, Department of Media Technology P.O.Box 15400, FI-00076 Aalto, Finland)
Tapio Lokki (Aalto University School of Science and Technology, Department of Media Technology P.O. Box 15400, FI-00076 Aalto, Finland)
Lauri Savioja (Aalto University School of Science and Technology, Department of Media Technology P.O. Box 15400, FI-00076 Aalto, Finland)

Invited paper (peer-reviewed): Special session on Computational Room Acoustics, O5a

The pros and cons of wave-based and ray-based room acoustics modelling methods are overviewed. Links between image-source, boundary element and radiance transfer methods are presented. The emphasis is on the main bottlenecks of each method. Accuracy, computational performance and applicability of the output of each method determine for modelling which part of the response they can be used. It is proposed that wave-based methods are used for low frequencies, image source methods for the early part of the room response for mid- and high frequencies, and radiance transfer methods for the rest of the response.

Introducing higher order diffraction into beam tracing based on the uncertainty relation

Uwe M. Stephenson (HafenCity University, Hamburg, Germany)

Invited paper (peer-reviewed): Special session on Computational Room Acoustics, O5b

The lacking simulation of diffraction is still a main problem of ray tracing in room and, even more, in city acoustics. The author´s approach to diffraction is an energetic one based on the uncertainty relation (UR). In many numerical experiments, it has been validated quite well at the single screen and the slit as reference cases, compared with Svensson´s exact wave-theoretical secondary edge source model. To avoid an explosion of computation time, the long-term objective is to combine this diffraction method once with Quantized Pyramidal Beam Tracing (QPBT). For preparation, it has therefore been modified to the more efficient beam tracing technique and with that has been tested for some additional configurations. Some improved by-pass-distance- and angle-dependent diffraction functions have been investigated to also fulfil the reciprocity principle. Recent experiments dealt with possible errors of unintended double diffraction, also with double diffraction at a cascade of two edges. Some new numerical results and comparisons with the reference model will be reported. The further aim is to investigate the general applicability of the model to higher order diffraction. This, unfortunately, has not been reached up to the deadline to submit this paper and therefore will be presented only orally.

A combination of the sound particle simulation and the radiosity method

Alexander Pohl (HafenCity University, Hamburg, Germany)
Uwe M. Stephenson (HafenCity University, Hamburg, Germany)

Invited paper (peer-reviewed): Special session on Computational Room Acoustics, O5c

In room and urban acoustics, ray tracing as well as, for the reverberation tail, radiosity based simulation methods are in use. Any implementation of diffraction into the sound particle simulation method, i.e. a variant of ray tracing, causes a split-up of sound particles and an explosion of computation time. To prevent that, a re-unification effect of sound energies has to be achieved as known from the radiosity method. For this purpose, the discretization of the walls into small patches is applied to the sound particle simulation method. This combination is called the sound particle radiosity method. In the main part of this paper the efficiency of the presented sound particle radiosity in investigated by deriving a statistical re-unification formula as a function of the main quantization parameter: the patch size. Furthermore the error due to quantization is described as a function of the patch size. It is shown, that smaller patches increase accuracy, but larger patches increase the efficiency. The smearing of echograms due to the receiver size mainly masks

the quantization error when the receiver size is at least 10 times the patch size. This investigation, restricted to 2D, serves as a feasibility test for quantized pyramidal beam tracing.

Fast and accurate geometric sound propagation using visibility computations
Anish Chandak (University of North Carolina at Chapel Hill, Chapel Hill, U.S.A.)
Lakulish Antani (University of North Carolina at Chapel Hill, Chapel Hill, U.S.A.)
Micah Taylor (University of North Carolina at Chapel Hill, Chapel Hill, U.S.A.)
Dinesh Manocha (University of North Carolina at Chapel Hill, Chapel Hill, U.S.A.)
Invited paper (peer-reviewed): Special session on Computational Room Acoustics, O5d
Geometric Acoustics (GA) techniques based on the image-source method, ray tracing, beam tracing, and ray-frustum tracing, are widely used to compute sound propagation paths. In this paper, we highlight the connection between these propagation techniques with the research on visibility computation in computer graphics and computational geometry. We give a brief overview of visibility algorithms and apply some of these methods to accelerate GA, specifically early specular reflections and finite-edge diffraction. Moreover, we survey our recent work on fast and accurate GA methods that use accurate and conservative visibility techniques. This includes: a) an algorithm for fast computation of early specular reflections using conservative from-point visibility computation; and b) a fast method for finite-edge diffraction using conservative from-region visibility computation. Our approach for computing specular reflections is based on the image-source method and we reduce the number of image sources by using conservative visibility computations. The edge diffraction computation is based on the well known Biot-Tolstoy-Medwin (BTM) diffraction model and we combine it with efficient algorithms for region-based visibility to significantly reduce the number of edge pairs that need to be processed for higher-order diffraction computation. We highlight the performance of these methods on many complex models. Our initial results indicate that we obtain considerable speedups over prior methods for accurate geometric sound propagation.

Use of GPUs in room acoustic modeling and auralization
Lauri Savioja (Aalto University School of Science and Technology, Department of Media Technology, Espoo, Finland; NVIDIA Research, Helsinki, Finland)
Dinesh Manocha (University of North Carolina, Chapel Hill, USA)
Ming C. Lin (University of North Carolina, Chapel Hill, USA)
Invited paper (peer-reviewed): Special session on Computational Room Acoustics, O5e
All room acoustic modeling techniques are computationally demanding due to the underlying complexity of sound propagation. Traditionally, all the modeling methods have been implemented for the central processing unit (CPU) of the computer. Recent trends in terms of programmable many-core processors or graphics processing units (GPU) is resulting in a paradigm shift. Modern GPUs are massively parallel processors with a different memory hierarchy, whose peak computational performance can be 10X more than that of current CPUs. In this paper, we give an overview of GPU architectures and address issues in designing suitable algorithms that map well to GPU architectures. The room acoustic modeling and auralization techniques are especially discussed in the light of possible GPU-based implementations. We also give a brief overview of recent methods for geometric and numeric sound propagation that offer one order of magnitude speedup over CPU-based algorithms.

Room acoustic modelling techniques: A comparison of a scale model and a computer model for a new opera theatre
Jens Holger Rindel (Odeon A/S, Scion DTU, Diplomvej 381, DK-2800 Kgs. Lyngby, Denmark)
Invited paper (peer-reviewed): Special session on Computational Room Acoustics, O5f
Today most acoustic consultants are using room acoustic computer models as a basis for their acoustic design. However, room acoustic scale modelling is still being used for the design in some major projects,

although the costs and the time needed are significantly larger than those related to computer modelling. Both techniques were used by the author in a project for a new opera theatre; first the acoustical design was based on computer simulations using the Odeon software, and next a 1:20 scale model was built and tested. In the paper the results obtained with the two different modelling techniques are compared, and in general a satisfactory agreement has been found. The advantages and drawbacks related to each of the modelling techniques are discussed.

The relationship between audience engagement and the ability to perceive pitch, timbre, azimuth and envelopment of multiple sources

David Griesinger (Consultant, 221 Mt Auburn St. #504, Cambridge, MA 02138, USA)

Contributed paper, O6

It is well known in psychology that sounds perceived as close to a listener engage our attention, while more distant sounds can be ignored. But the physical properties of sound that lead to engagement are poorly understood. The phenomenon is well known by directors of cinema and drama, who demand that theatres and sound systems have high presence, and not just adequate intelligibility. This is achieved by bringing the audience close to the performers, attenuating both early and late reflections, and using highly directional loudspeakers for cinema. When sounds are perceived as distant it is not just engagement that suffers. Precise localization of instruments in ensembles becomes impossible, and instrumental voices – distinct in a historic hall – become blended into mere harmonies. Historic concert venues tended to be small, with sound absorbing stages and audience areas. Sonic intimacy and clarity of musical lines was taken for granted. But the physical properties that make a sound seem close to a listener are poorly under-stood, and there is no current acoustic measure for specifying the type of clarity that provokes audience attention. An overly reverberant, “well blended” sound has become the design goal for modern chamber music and orchestral venues, even though a few great halls demonstrate that it is possible to have both clarity and reverberation at the same time over a wide range of seats. This paper describes the physics of sound that provides engagement, and how reflections interact to reduce it. An impulse response based measure for engagement is described, along with a means of determining the degree of engagement from live recordings of speech. Time and equipment permitting, the author will demonstrate that the right combination of direct sound and reflections can provide engagement, localization, reverberation, and envelopment at the same time. The improvement in sound quality is dramatic.

A framework for characterizing sound field diffusion based on scattering coefficient and absorption coefficient of walls

Toshiki Hanyu (Department of Construction, Junior College, Nihon University 7-24-1 Narashinodai, Funabashi, Chiba 274-8501, Japan)

Keynote address (peer-reviewed), K3

This paper describes the development of a theoretical framework for quantitatively characterizing sound field diffusion based on scattering coefficient and absorption coefficient of walls. The concepts of equivalent scattering area, equivalent scatter reflection area, average scattering coefficient and average scatter reflection coefficient are introduced in order to express all walls' capability of scatter in a room. Using these concepts and the mean free path, scatter-to-absorption ratio, mean scatter time and diffusion time are defined in order to evaluate degree of diffusion of a space. Furthermore the time variation of specular and scattered components in a room impulse response is formulated. The verification of these characterization methods was performed with computer simulations based on the sound ray tracing method. The results supported that the ideas presented are basically valid.

Open measurements of edge diffraction from a noise barrier scale model

Dirk Schröder (Institute of Technical Acoustics, RWTH Aachen University, 52066 Aachen, Germany)
U. Peter Svensson (Centre for Quantifiable Quality of Service in Communication Systems, NTNU, 7491 Trondheim, Norway)
Michael Vorländer (Institute of Technical Acoustics, RWTH Aachen University, 52066 Aachen, Germany)

Contributed paper (peer-reviewed), P6a

Until today, all known simulation methods for the wave phenomenon of edge diffraction are just approximations, based on either Geometrical Acoustics or the numerical solving of the wave equation. Although these methods work fine for simple test scenarios and a certain frequency range, they fail to simulate the effect of diffraction in its whole complexity. This leads to false predictions especially for more complex geometries where the influence of multiple wave diffraction and sound scattering has to be taken into account as well. Consequently, huge effort is currently put into the development of improved simulation methods. Here, a basic need is an all-embracing validation of simulation results, which also includes the comparison with real-world measurements. Unfortunately, there is a lack of such data which is the reason why the Institute of Technical Acoustics (ITA), RWTH Aachen University, Germany, and the Centre for Quantifiable Quality of Service in Communication Systems (Q2S), NTNU Trondheim, Norway, have started an initiative called *openMeasurements*, which is aimed to be an internet platform for free acoustic measurement data of any kind, together with their respective simulation models (CAD-model, detailed information on sources and receivers, material data) and helpful tools. As initial step, various measurement series of a scaled-down model of a noise barrier were carried out. These series aim to give researches, developers, and common application users, the possibility to thoroughly test their prediction models of edge diffraction.

The measurements were carried out in a full anechoic chamber and a turntable was used to rotate the scale-model during the measurements in steps of one degree. The scale-model was constructed with a changeable ground layer in oder to massively influence the object's acoustical properties and, thus, create measurement datasets that considerably differ. Here, datasets for five different ground layers were obtained: 3 absorbers, 1 rigid surface and 1 self-constructed skyline-diffuser. A skyline diffuser was chosen as it is a well reproducible geometrical pattern, which enables a simulation of sound scattering in two ways: stochastic and deterministic. In this contribution, detailed information on the measurement setup is given and measurement procedures are described thoroughly. Measurement uncertainties are briefly discussed and first comparisons with simulations are presented. All measurements together with geometrical models of the scale-model (with/without diffuser), detailed information on sources and receivers, material data (absorption- and scattering coefficients) and useful Matlab tools are freely available for download (www.openmeasurements.net).

The role of sound diffusing surfaces in the quality of the architectural space

Fausto E. Rodriguez-Manzo (Laboratorio de Análisis y Diseño Acústico (Acoustic Design and Analysis Laboratory), División de Ciencias y Artes para el Diseño, (Division of Design Sciences and Arts), Departamento de Procesos y Técnicas Universidad Autónoma Metropolitana-Azcapotzalco, México D.F., México)
Elisa Garay-Vargas (Laboratorio de Análisis y Diseño Acústico (Acoustic Design and Analysis Laboratory), División de Ciencias y Artes para el Diseño, (Division of Design Sciences and Arts), Departamento de Procesos y Técnicas Universidad Autónoma Metropolitana-Azcapotzalco, México D.F., México)

Contributed paper (peer-reviewed), P6b

Architects usually do not consider sound as an important element in architectural design. However there is no doubt that sound is a key factor in space perception. By simply closing our eyes we realize the

importance of sound, compared to using our sight only. Visual aspects such as light, materials, textures and colors are generally the elements that guide architects creative ideas. Today diffusion surfaces in concert halls are widely used, contributing to the improvement of music programs acoustic quality and to the improvement of the visual aspects of halls. This means that sound diffusers can significantly improve the architectural quality of any space by incorporating sound quality design as well as visual features. This paper presents the authors research on the diffusion of sound in surfaces and the impact these have on the reverberation time of an architectural space using a scale model approach and a real space comparison. We take into account that reverberation is understood through various parameters of the acoustic quality of the architectural space. This analysis has been developed from the architectural point of view, considering the use of sound diffusion as an architectural design concept. Inside this paper the development of the experiment done and the results of it are reported.

Real-valued amplitude reflection grating designs for sound diffusion
James Heddle (James Heddle Acoustic Design, Brisbane, Australia)
Contributed paper (peer-reviewed), P6c
This paper presents the results of investigations into real-valued alternatives to binary or n-ary based amplitude reflection gratings for sound diffusion. The limitation of these gratings is discussed together with proposed methods of improving performance.

Architectural and acoustic features of the caisson ceiling in traditional Chinese theatres
Jie He (School of Architecture, University of Sheffield, Sheffield S10 2TN, United Kingdom)
Jian Kang (School of Architecture, University of Sheffield, Sheffield S10 2TN, United Kingdom)
Contributed paper (peer-reviewed), P6d
One of the great features of traditional Chinese theatres is the caisson ceiling, which is a sunken panel placed in the centre of the stage ceiling. Although caisson ceilings were rare in general traditional Chinese architecture, for one particular architectural type, traditional Chinese theatres, they were rather common, especially in southern China. Firstly, this paper briefly analyses the historical origins, cultural connotation and evolution of caisson ceilings, and categorises the caisson ceilings in traditional Chinese theatres based on its architectural forms. Since there are two opinions about the effectiveness of caisson ceilings in traditional Chinese theatres, namely concentrating or diffusing sounds, in the main part of this paper, detailed analysis of various architectural acoustic features of such caisson ceilings has been carried out, based on computer simulation. The initial results suggest that because of the hemispherical shape, caisson ceilings tend to have the acoustic function of concentrating sounds. In the meantime, caisson ceilings are beneficial for providing early reflections to the actors and audience standing close to the stage.

Acoustical renovation of small auditoria using sound diffusers
Chun Ki Seo (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Yong Hee Kim (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Pyoung Jik Lee (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Jin Yong Jeon (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Contributed paper, P6e
This paper describes the acoustical design for two small halls using diffusers: the Chamber Hall (450 seats) and M-theater (630 seats) in Sejong Performing Arts Center, Seoul. The Chamber Hall was completely refurbished as a re-cital hall with a volume of 3,200 m^3 from a rectangular conference space. The saw-tooth

shaped wall reflectors were designed for sound diffusion. The M-Theater was also renovated for musical and small opera performances as a live and intimate space; its volume of audience area was 4,800 m^3 including spaces above ceiling reflectors. The box-type diffuser profile in the M-Theater was designed using Glass Fiber Reinforced Gypsum in consideration of middle to high frequency sound diffusion. The measured scattering coefficient of the diffuser was 0.75 at the average of 500 to 3,150 Hz. The effects of diffusers in both halls were investigated through 1:25 scale models and actual hall measurements.

The acoustic design of the Teatro Eschilo, Gela (Italy)
Lamberto Tronchin (DIENCA – CIARM, University of Bologna, Viale Risorgimento 2, Italy)
Valerio Tarabusi (DIENCA – CIARM, University of Bologna, Viale Risorgimento 2, Italy)
Contributed paper, P6f
The "Teatro Eschilo", in the town of Gela, Sicily, Italy, was built in 19th century, and refurbished many times in the early 20th century. During those refurbishments the main hall was completely modified: a huge balcony on two rows made in concrete, substituted the original 5 orders of balconies, and the proscenium was totally redesigned. The walls were heavily upholstered, to limit the reflection of the concrete, and a fresco of the School of the Sicilian painter Guttuso was painted in the ceiling. After a while people started to complain about the acoustics. Moreover, after the Second World War, the theatre was slowly abandoned and it definitely closed in 1982. The original acoustics of the theatre was poor. The Opera was not fully appreciated, and musical performances were strongly unsatisfying. Therefore, the reopening of the theatre would have required to be accomplished by an acoustical design, which could enhance the reverberation, limit the focalisation and increase the strength in the far seats. In 2000 an architectural design was proposed. The acoustical project consisted in a set of diffusing panels mainly located in the stage, and in a treatment in the ceiling and in the lateral walls. The panels were designed following Schroeder's number theory, and the location in the theatre was analysed by means of a numerical code. The results of numerical calculations, as well as examples of the panels, are here presented.

***In situ* measurement methods for characterising sound diffusion**
Isabelle Schmich (Université Paris-Est, Centre Scientifique et Technique du Bâtiment, 24 rue Joseph Fourier, 38400 Saint Martin d'Hères, France)
Nathalie Brousse (218 rue de la Roche – 86160 Gençay)
Invited paper (peer-reviewed): Special session on Diffusers and Diffusion, O7a
With the aim of defining a new *in situ* method of diffusion measurement, two methods have been investigated. The first one is based on the measurement of a mono-dimensional reverberation time between two parallel plates and gives an evaluation of a scattering coefficient. This field method has been tested through computer simulation and shows high sensitivity to experimental conditions. The experimental set-up has been realized and laboratory measurements conducted. The second method is focused at the scale of a concert hall and proposes new parameters which could lead to a new global diffusivity index. It has been simulated with a computer model with various diffuser arrangements. These two methods are complementary and if further developed could lead to efficient tools for evaluating and optimizing diffusion in real concert halls.

The potential for phononic sound diffusers (PSD)
Javier Redondo (Institut d'Investigació per a la Gestió Integrada de Zones Costaneres, Universitat Politècnica de València, C/Paranimf 1, 46730 Grau de Gandia, Spain)
Rubén Picó (Institut d'Investigació per a la Gestió Integrada de Zones Costaneres, Universitat Politècnica de València, C/Paranimf 1, 46730 Grau de Gandia, Spain)
Víctor Sánchez-Morcillo (Institut d'Investigació per a la Gestió Integrada de Zones Costaneres, Universitat Politècnica de València, C/Paranimf 1, 46730 Grau de Gandia, Spain)
Invited paper: Special session on Diffusers and Diffusion, O7b
Although periodic structures theory gave rise to sound diffusers almost 40 years ago, it has been only in recent years when several authors regarded the possible application of a particular kind of periodic structures, phononic crystals, in the field on room acoustics. This paper explores the possible application of periodic structures used as sound diffusers in rooms. Preliminary simulations, carried out with FDTD, shows that due to the inherent time spreading provided by a periodic structure, they can be used to reduce, or even to eliminate, pernicious effects associated with the low frequency modes of the room.

Diffuser design in concert halls using scale models
Jin Yong Jeon (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Yong Hee Kim (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Hyung Suk Jang (Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea)
Invited paper: Special session on Diffusers and Diffusion, O7c
Concert hall scale models with different scale factors were tested to investigate the locations and profiles of the dif-fusers. In-situ diffuseness of the scale models was measured by "number of peaks (Np)" from the impulse responses recorded from the scale model halls. Diffuser locations and profiles were determined to yield maximum Np using 1:25 scale model, when omni-directional (hemisphere) diffusers were used. Scattering/diffusion coefficients of 1:10 diffuser specimen were measured and QRD-type horizontal diffusers were designed for the lateral walls close to stage in 1:10 scale model halls.

How acousticians listen
Leo Beranek (776 Boylston Street, Boston MA 02199, USA)
J. Christopher Jaffe (Acentech Studio A, Boston MA, USA)
Tateo Nakajima (Artec Consultants Inc, New York NY, USA)
Eckhard Kahle (Kahle Acoustics, Bruxelles, Belgium)
R. Lawrence Kirkegaard (Kirkegaard Associates, Chicago IL, USA)
Pamela Clements (Clements Acoustics Design Associates, Melbourne Vic, Australia)
Invited paper: Special session on How Acousticians Listen, O8
Acousticians approach the critical task of listening to the acoustics of a performance space, such as a concert hall or theatre, in a wide variety of ways. Critical decisions about room acoustics design are based on our listening perceptions and judgments. It appears straightforward: we listen to inform the process of correlating aural perceptions with the room form, shaping and materials, and with various acoustic parameters. Our listening is thus an active process that is a vital part of the work of acoustic design. There's more going on than this, however. Acousticians bring a wide range of backgrounds and interests to their work, which can powerfully influence their approach to the task of listening, and thus the framework in which their perceptions are interpreted and applied. Some of us tend to focus more on listening for reflection patterns and frequency response in the room, others focus on listening specifically for different acoustic parameters, while others give primacy to the performance itself and how it would sound in an acoustically excellent (and appropriate) space, vs what is actually heard. With such different approaches to

listening, it seems worth asking how design outcomes are being influenced. Does listening within one framework lead to misconceptions in another? How do our preconceptions about music, acoustics, or architecture influence what we hear? Is formal training warranted specifically for listening in performance spaces of different sizes and uses? This ISRA session is a forum, with short presentations by five eminent acousticians, followed by questions and discussion among the presenters and the audience.

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