Room acoustic modelling techniques: A comparison of a scale model and a computer model for a new opera theatre

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Odeon A/S
Outline

• The project
• Computer model
• Results from computer simulations
• Scale model and measurement technique
• Materials and adjustment of absorption
• Results from scale model measurements
• Comparison of results and methods
• Conclusion
The project

Ankara Congress and Cultural Centre
Opera theatre with approx 1400 seats
Architect: Ö zgür Ecevit, Turkey
Acoustic consultant: Jordan Akustik and J.H. Rindel
Design goals

ISO 3382 parameters (with full audience)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Recommended range</th>
<th>Just noticeable difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>T30</td>
<td>1.5 to 2.2 s</td>
<td>5%</td>
</tr>
<tr>
<td>EDT</td>
<td>1.5 to 2.2 s</td>
<td>5%</td>
</tr>
<tr>
<td>G</td>
<td>-2 to +6 dB</td>
<td>1 dB</td>
</tr>
<tr>
<td>C80</td>
<td>-2 to +4 dB</td>
<td>1 dB</td>
</tr>
<tr>
<td>LF</td>
<td>0.2 to 0.4</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Computer model – room model

Model in the final phase 3. Design and materials were adjusted according to results from the previous phases.

2 source positions
stage pit
7 receiver positions
main floor balconies
Scattering coefficients (500 1000 Hz):
0.6 – Audience, orchestra, back walls, balcony bottoms
0.1 – All other surfaces
Calculation results

Average of 7 receiver positions

ISRA Melbourne 2010
Calculation results

Average of 7 receiver positions
EDT – Grid response

1 kHz octave Source on stage

ISRA Melbourne 2010
Strength G – Grid response

1 kHz octave Source on stage
Clarity C80 – Grid response

1 kHz octave Source on stage
1 kHz octave Source on stage
Scale model 1:20
Equipment

- Sound source: Electric spark source (designed at DTU)
- Useful frequency range: 1.6 – 110 kHz, corresponding to 80 – 5500 Hz, i.e. 125 – 4000 Hz octave bands in scale 1:20
- Microphone: BK4136 ¼”-microphone, a BK2636 measuring amplifier and a Rockland 852 dual high/low-pass filter
- MIDAS software for measurements and analysis
Measurement setup
Spectrum of spark source
(Frequency / 20)
Air conditions

- Temperature and humidity was kept very stable. RH around 60%
- The MIDAS measurement system adjusted the impulse response to compensate for the excessive air attenuation at the high frequencies
Audience

- Wooden fibre plate glued to a styrofoam back, in which the shapes of the “heads” of the audience are cut out.

Some of the surfaces of the front and back were covered with a layer of tape, in order to adjust the absorption.
Absorption of model audience

Audience on occupied chairs, medium upholstered

Adjustment of absorption

ANKARA OPERA HOUSE, PHASE III
Closed stage opening - Source in pit

Reverberation time, T30 (s)

Frequency, Hz

Final
Simulated
Model 1
Model 2

ISRA Melbourne 2010
Adjustment of absorption

Low frequency absorption added

Ceiling in the auditorium with additional absorption

- Principle: To obtain the correct reverberation time in the relevant frequency range, although the contribution from air attenuation is higher in the model than in the real hall
Adjustment of scattering

Wrinkled foil attached to the walls to represent a diffusing treatment
RT – Source on stage

ANKARA OPERA HOUSE, PHASE III

Source on stage

Average of 7 receiver positions

ISRA Melbourne 2010
RT – Source in pit

ANKARA OPERA HOUSE, PHASE III
Source in pit

Average of 7 receiver positions

Reverberation time, T30 (s)

Frequency, Hz

Measured
Simulated

Average of 7 receiver positions

ISRA Melbourne 2010
EDT – Source on stage

ANKARA OPERA HOUSE, PHASE III
Source on stage

Average of 7 receiver positions
EDT – Source in pit

ANKARA OPERA HOUSE, PHASE III
Source in pit

Average of 7 receiver positions
G – Source on stage

ANKARA OPERA HOUSE, PHASE III
Source on stage

Average of 7 receiver positions

ISRA Melbourne 2010
G – Source in pit

ANKARA OPERA HOUSE, PHASE III
Source in pit

Average of 7 receiver positions
C80 – Source on stage

ANKARA OPERA HOUSE, PHASE III
Source on stage

Average of 7 receiver positions
C80 – Source in pit

ANKARA OPERA HOUSE, PHASE III
Source in pit

Average of 7 receiver positions
Comparison of methods

Receiver 3:
Sound propagation elevated over audience surface, no attenuation of direct sound
Reflection from audience surface
Comparison of methods

Receiver 3:
Sound propagation close to audience surface (attenuation missing in simulation)
No direct sound; Diffraction across pit wall (Odeon ver. 10)
C80 – comparison of methods

Stage to main floor

Pit to main floor

C80 (dB) @ 500 Hz

Receiver position

ISRA Melbourne 2010
## Discussion - 1

<table>
<thead>
<tr>
<th></th>
<th>Scale model</th>
<th>Computer model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room model detailing</td>
<td>High degree of detail possible (but expensive)</td>
<td>Simplified geometry preferred High degree of detail possible</td>
</tr>
<tr>
<td>Materials</td>
<td>Absorption approximated</td>
<td>Absorption data accurate (if available)</td>
</tr>
<tr>
<td>Scattering</td>
<td>Included with detailed modelling</td>
<td>Scattering coefficients assigned to surfaces with simplified details</td>
</tr>
<tr>
<td>Diffraction</td>
<td>Included</td>
<td>Approximated or missing in some cases</td>
</tr>
<tr>
<td>Attenuation of sound propagating across audience area</td>
<td>Included with detailed modelling of audience</td>
<td>Not included (yet)</td>
</tr>
</tbody>
</table>
## Discussion - 2

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<thead>
<tr>
<th></th>
<th>Scale model</th>
<th>Computer model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air attenuation</td>
<td>Compensation needed (less abs. in materials or impulse response boosted)</td>
<td>Accurate (calc. from temperature and RH)</td>
</tr>
<tr>
<td>Frequency range</td>
<td>Limited at low and high frequencies</td>
<td>Full audio range</td>
</tr>
<tr>
<td>Reverberation time</td>
<td>Used for calibration. Absorption of materials adjusted to meet expected RT</td>
<td>Predicted by simulation</td>
</tr>
<tr>
<td>EDT, G, C80 ...</td>
<td>From measured impulse response</td>
<td>From calculated impulse response</td>
</tr>
<tr>
<td>LF, IACC</td>
<td>Special miniature transducers needed</td>
<td>From calculated impulse response (3D)</td>
</tr>
</tbody>
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## Discussion - 3

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<thead>
<tr>
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<th>Computer model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Auralisation</strong></td>
<td>Quality limited by transducers</td>
<td>High quality possible. Any HRTF may be applied</td>
</tr>
<tr>
<td><strong>Reproduction through loudspeakers</strong></td>
<td>Not possible</td>
<td>Ambisonics or n-channel surround</td>
</tr>
<tr>
<td><strong>Sources with special directivity (musical instruments)</strong></td>
<td>Possible, but difficult</td>
<td>Possible. Application of directivity data or multi-channel auralisation</td>
</tr>
<tr>
<td><strong>3D analysis of early reflections</strong></td>
<td>Possible with laser beam and light-reflecting surfaces</td>
<td>Easy, coupled to reflectogram</td>
</tr>
</tbody>
</table>
## Discussion - 4

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<th>Computer model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Echo and flutter echo detection</strong></td>
<td>Inspection of impulse response</td>
<td>Inspection of impulse response. Auralisation of impulsive sound</td>
</tr>
<tr>
<td><strong>Colouration</strong></td>
<td>Not possible</td>
<td>Possible with high quality auralisation</td>
</tr>
<tr>
<td><strong>Detection of weak spots in the audience area</strong></td>
<td>Not realistic to cover all seats by measurements</td>
<td>Possible through grid mapping of all parameters</td>
</tr>
<tr>
<td><strong>Grid mapping of results</strong></td>
<td>Not possible</td>
<td>High resolution grids possible (long calculation time)</td>
</tr>
</tbody>
</table>
Conclusion

• Both methods have weaknesses and advantages
• Results: No big difference between measured and simulated room acoustic parameters
• Main problems in scale models:
  – Transducers (directive sources, dummy head)
  – Auralisation with sufficient quality
• Main problems in computer models
  – Data for scattering surfaces; can be measured in scale model reverberation chamber (ISO 17497-1)
  – Simulation of the attenuation of sound propagation across the audience area