Sound reflections in an Urban Context
The influence of façades on urban noise levels
Introduction

- Graduation goal
- Background information
- Computer simulations
- Scale model measurements
- Façade designs
- Conclusions
Problem statement

• Health risk: environmental noise
  Causes annoyance, stress, 1.8% of the heart attacks

• Social costs: 0.4% of GDP (EU)

• Sound reflections have a significant influence
  Changes levels +3 to -8 dB
Research question

• How can an existing façade be adapted in such a way that the impact of the noise reflected by it will be reduced?

• Focus on existing location

  Herman Gorterhof, Delft
Research question

- Façade to redesign
- Nearby road (noise source)
- Measured courtyard area
Decibel levels (dB)

Sound perception

• Normal conversation: 60 dB
• Twice as loud: +10 dB

Noise level rating

• Background noise levels (caused by traffic for example)
• Preferred: ≤48 dB(A)

<table>
<thead>
<tr>
<th>GES-score</th>
<th>Environmental health quality</th>
<th>Noise level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$L_{den}$ (dB(A))</td>
</tr>
<tr>
<td>0</td>
<td>Very good</td>
<td>&lt; 43</td>
</tr>
<tr>
<td>1</td>
<td>Good</td>
<td>43 – 47</td>
</tr>
<tr>
<td>2</td>
<td>Reasonable</td>
<td>48 – 52</td>
</tr>
<tr>
<td>3</td>
<td>Pretty mediocre</td>
<td>48 – 52</td>
</tr>
<tr>
<td>4</td>
<td>Moderate</td>
<td>53 – 57</td>
</tr>
<tr>
<td>5</td>
<td>Very moderate</td>
<td>58 – 62</td>
</tr>
<tr>
<td>6</td>
<td>Insufficient</td>
<td>63 – 67</td>
</tr>
<tr>
<td>7</td>
<td>More than insufficient</td>
<td>68 – 72</td>
</tr>
<tr>
<td>8</td>
<td>Very insufficient</td>
<td>&gt; 73</td>
</tr>
</tbody>
</table>

Sound propagation*

- Directly hitting the façade
- Absorb it at the façade

*in Dutch: geluidsverspreiding

Kotzen & English (2009), Kranendonk and Nijs (1979)
Sound propagation

- Reflecting from the façade
- Reflect elsewhere or scatter

Buro Lubbers (2015), Topocast (2012), Kranendonk and Nijs (1979)
Sound propagation

- Sound diffracting over and around the building
- Change building edge (roof)

van Renterghem (2015), Kranendonk and Nijs (1979)
Case study location

- Herman Gorterhof, Delft
  - Nearby busy road
- Sound levels mostly influenced by reflections
- Conducted on-site measurements
Computer simulations

- CATT Acoustics
- Simplified model
- Used on-site measurements
- Several façade solutions:
  - Absorption
  - Scattering
  - Reflection (up, back, down)
Computer simulations

- Absorption
- Reflection upward
  - 10 degree
  - 45 degree
  - ‘optimal’ degree
Computer simulations

• Absorption

• Reflection upward
  – 10 degree
  – 45 degree
  – ‘optimal’ degree
Simulation results

- Acoustical improvements
  - Courtyard improvements
  - No diffraction (yet)
- Architectural impact
  - Element size
  - Applied per X floors

Simulation results:

- Acoustical improvements:
  - Courtyard improvements: 3.5 dB(A)
  - No diffraction (yet) 4.1 dB(A)

- Architectural impact:
  - Element size: 3.8 dB(A), 4.4 dB(A), 5.6 dB(A)
  - Applied per X floors: 3.9 dB(A), 4.5 dB(A)
Scale model measurements

- Small semi-anechoic room
  Applied Physics TU Delft
- 1:50 scale model
  - Up to 800 Hertz
- Façade solutions based on computer simulations
  - Absorption, upward and backward reflection
Scale model measurements

Courtyard setup

Diffraction setup
Measurement results

- Courtyard improvements
  - opti° upward reflection

<table>
<thead>
<tr>
<th>Angle</th>
<th>Absorption</th>
<th>Measurement 1</th>
<th>Measurement 2</th>
<th>Measurement 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>abs</td>
<td></td>
<td>2.1 dB(A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10°</td>
<td></td>
<td>3.5 dB(A)</td>
<td>4.5 dB(A)</td>
<td></td>
</tr>
<tr>
<td>45°</td>
<td></td>
<td>3.7 dB(A)</td>
<td>4.6 dB(A)</td>
<td></td>
</tr>
<tr>
<td>opti°</td>
<td></td>
<td>4.6 dB(A)</td>
<td>5.8 dB(A)</td>
<td></td>
</tr>
</tbody>
</table>
Measurement results

- Courtyard improvements
  - \( \text{opti}^{\circ} \) upward reflection
- Diffraction
  - Absorbing solution
  - \( 10^{\circ} \) upward reflection

\[
\begin{align*}
\text{abs} & : 2.6 \text{ dB(A)} \\
10^{\circ} & : -0.7 \text{ dB(A)} \\
45^{\circ} & : -0.8 \text{ dB(A)} \\
\text{opti}^{\circ} & : -2.8 \text{ dB(A)} \\
10^{\circ} & : 0.0 \text{ dB(A)} \\
45^{\circ} & : -2.6 \text{ dB(A)} \\
\text{opti}^{\circ} & : -2.5 \text{ dB(A)}
\end{align*}
\]
Measurement results

- **opti° upward reflection**
  - Causes the most diffraction

- **Absorbing solution**
  - Relatively low improvements

- **10° upward reflection**
  - Improve by adding absorption

<table>
<thead>
<tr>
<th>Reflection Angle</th>
<th>Measured Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>opti° upward</td>
<td>5.8 dB(A)</td>
</tr>
<tr>
<td>Absorbing</td>
<td>3.5 dB(A)</td>
</tr>
<tr>
<td>10° upward</td>
<td>4.5 dB(A)</td>
</tr>
</tbody>
</table>
Design requirements

• Reduce sound reflections
• Fit in current building structure
• Absorbing materials
• Added value
  – Interesting façade
  – Shading
  – Reduce indoor noise levels

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- Reduce sound reflections
- Fit in current building structure
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- Added value
  - Interesting façade
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  - Reduce indoor noise levels

### Design requirements

- **Absorbing materials**
  - High absorption coefficient
  - Impact resistant

<table>
<thead>
<tr>
<th></th>
<th>Quietstone</th>
<th>Perforated panel</th>
<th>Brickwork</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NRC values</strong></td>
<td>0,90</td>
<td>0,90</td>
<td>0,05</td>
</tr>
<tr>
<td><strong>Costs (indication)</strong></td>
<td>±€70 per m²</td>
<td>±€110 per m²</td>
<td>±€20 per m²</td>
</tr>
<tr>
<td><strong>Architectural looks</strong></td>
<td>+</td>
<td>-/+</td>
<td>+</td>
</tr>
<tr>
<td><strong>Impact resistant</strong></td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td><strong>Self-supporting</strong></td>
<td>-/+</td>
<td>+</td>
<td>++</td>
</tr>
</tbody>
</table>

Façade designs

• Design based on simulations and measurements:
  – Sound absorbing design
  – Sound reflecting design
  – Sound reflecting and absorbing design
Sound absorbing design

- Absorbing elements
  - Façade cladding; tiles
  - Parapet; perforated absorber
  - Tilted balcony ceiling; tiles
- Red sun shade elements (sliding)
- Relatively simple design
- Expensive absorbing materials
Sound absorbing design

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Sound reflecting design

- Absorbing elements
  - Façade cladding; tiles
- Balcony closed off
  - Reflects sound
  - Reduces indoor sound
- Red sun shade elements
- Relatively complex design
Sound reflecting design

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Sound reflecting design

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Combined design

• Absorbing elements
  – Façade cladding; tiles
  – Parapet; perforated absorber
  – Tilted balcony ceiling; tiles
• Tilted lower two floors
• Red sun shade elements
• Expensive absorbing materials
Combined design

• Absorbing elements
  – Façade cladding; tiles
  – Parapet; perforated absorber
  – Tilted balcony ceiling; tiles
• Tilted lower two floors
• Red sun shade elements
• Expensive absorbing materials
Façade design

- Rating using several aspects
  - Focus on improving sound levels

<table>
<thead>
<tr>
<th>Design</th>
<th>Architectural looks (shape)</th>
<th>Structural complexity</th>
<th>Costs</th>
<th>Reusability (sustainability)</th>
<th>Sound level improvements</th>
<th>Diffraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound absorbing</td>
<td>+/-</td>
<td>++</td>
<td>-</td>
<td>+</td>
<td>3,5 dB(A)</td>
<td>++</td>
</tr>
<tr>
<td>Upward sound reflecting</td>
<td>++</td>
<td>--</td>
<td>--</td>
<td>-/+</td>
<td>5,3 dB(A)*</td>
<td>--</td>
</tr>
<tr>
<td>Absorbing and reflecting</td>
<td>+</td>
<td>-/+</td>
<td>-</td>
<td>+</td>
<td>4,3 dB(A)*</td>
<td>-/+</td>
</tr>
</tbody>
</table>

*the effect of sound absorbing materials is not included for these measurements
How can an existing façade be adapted in such a way that the impact of the noise reflected by it will be reduced?
Conclusions

• Several ways to reduce sound reflections
  – Absorption (material)
  – Reflection (shape)

• Proposed combined design
  – Average ±5 dB(A) improvements
  – Up to 10 dB(A) at certain locations
  – Low impact on diffractions
Discussion and recommendations

• More detailed simulations and measurements
  – Influence of trees and other (smaller) objects
  – Investigate diffraction/weather effects in more details
  – Reduce other ‘errors’/differences

• Focus more on architectural parameters
  – Acoustically focused research
Sound reflections in an Urban Context
The influence of façades on urban noise levels

Building Technology
January 27, 2016
Jelmer Niesten 4010612
Social costs (simplified calculation)

- GDP NL per person: €39,634 (tradingeconomics.com, 2014)
- Social costs: 0.4% of GDP (WHO, 2011)
  - (€159 per person or) €317 for two persons, per year
  - (€7,927 or) €15,854 for 50 years
- Façade per house: 37m²
  - (€214 or) €428 available per m²
- Perforated sound absorber (worst case price): €355 per m²