



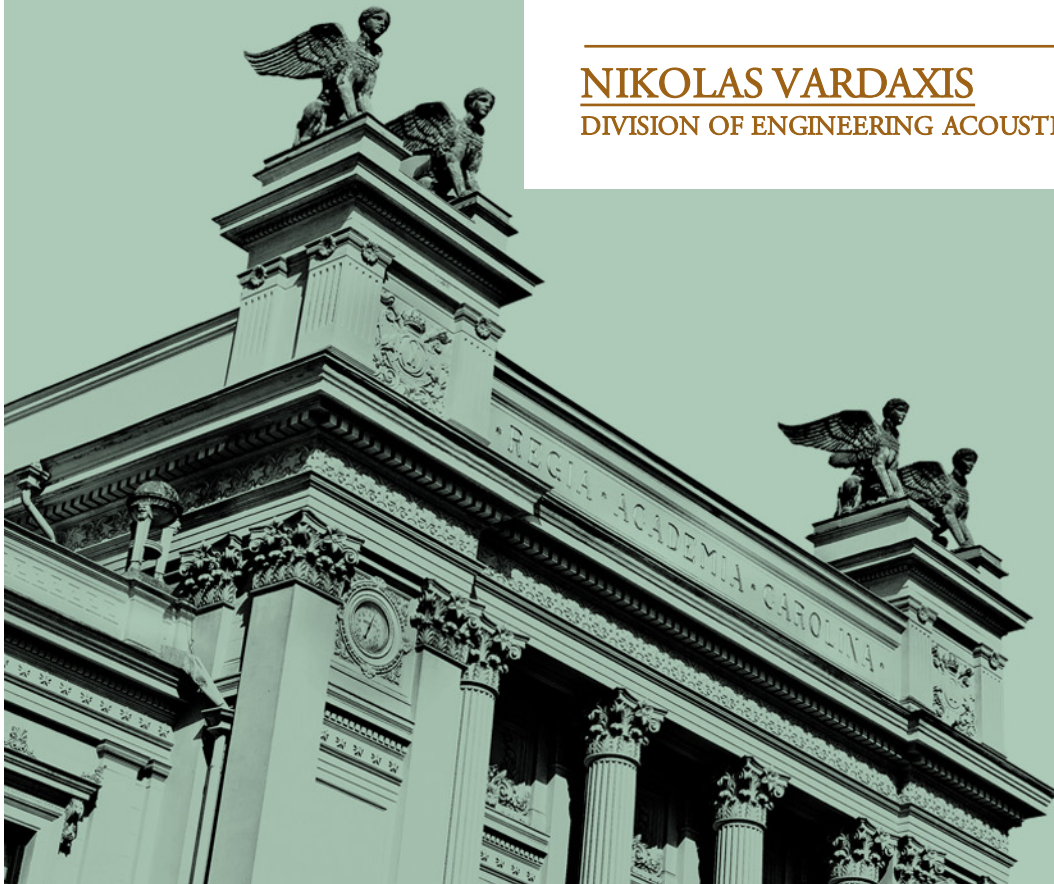
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Acoustics (VTAN01)

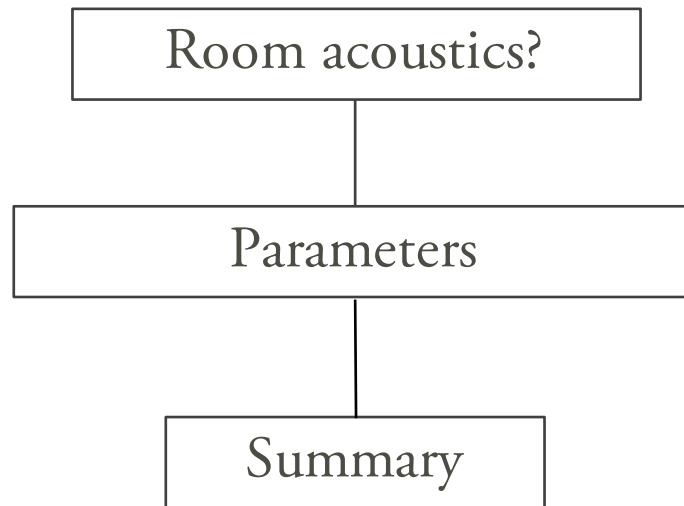
– Room Acoustics (1:Parameters)

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Outline

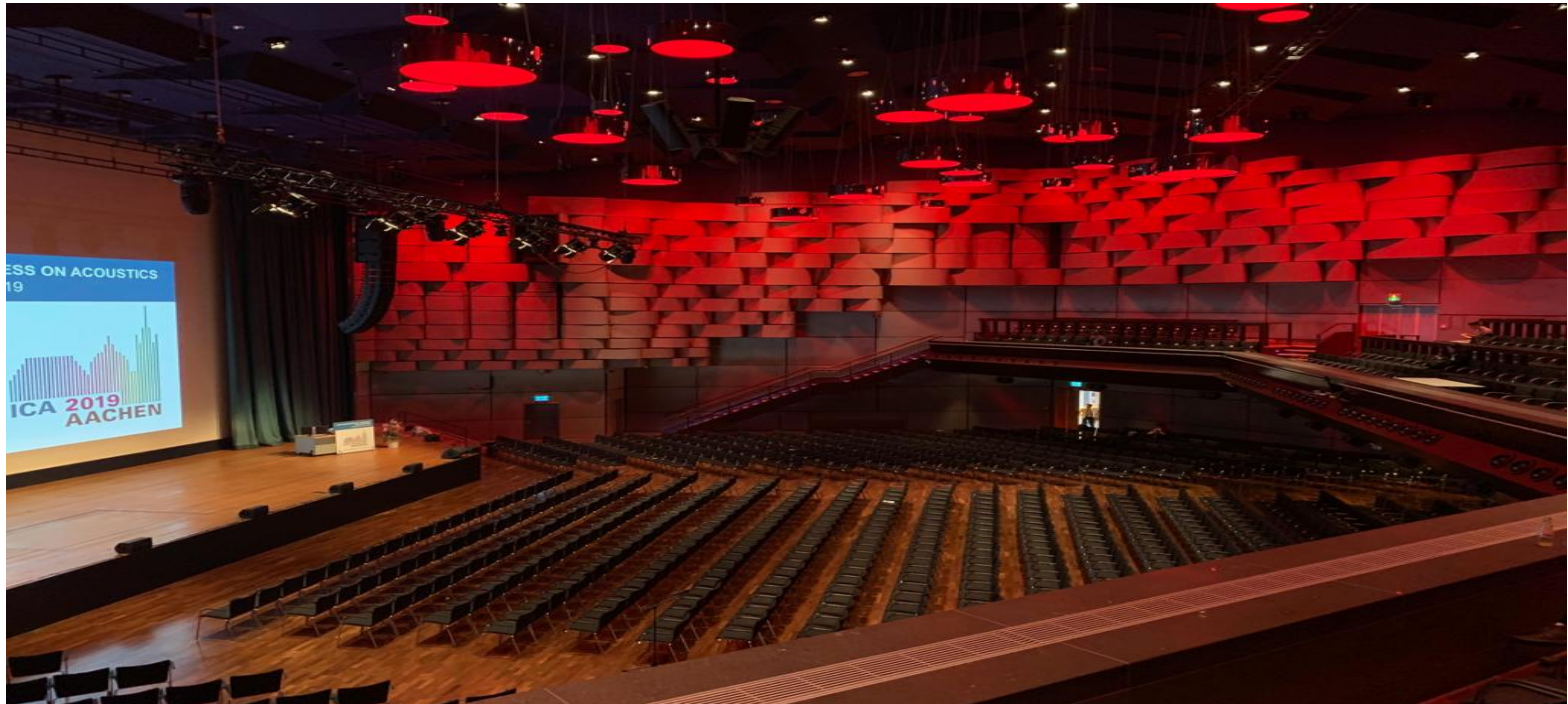


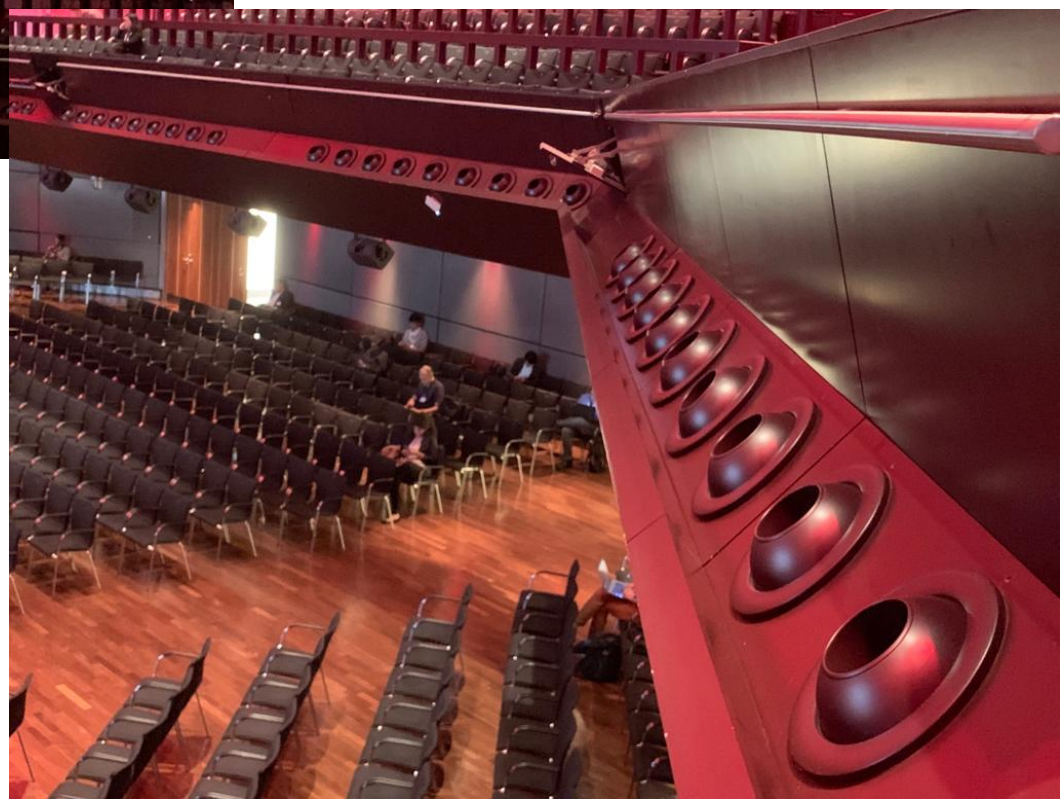
Basics

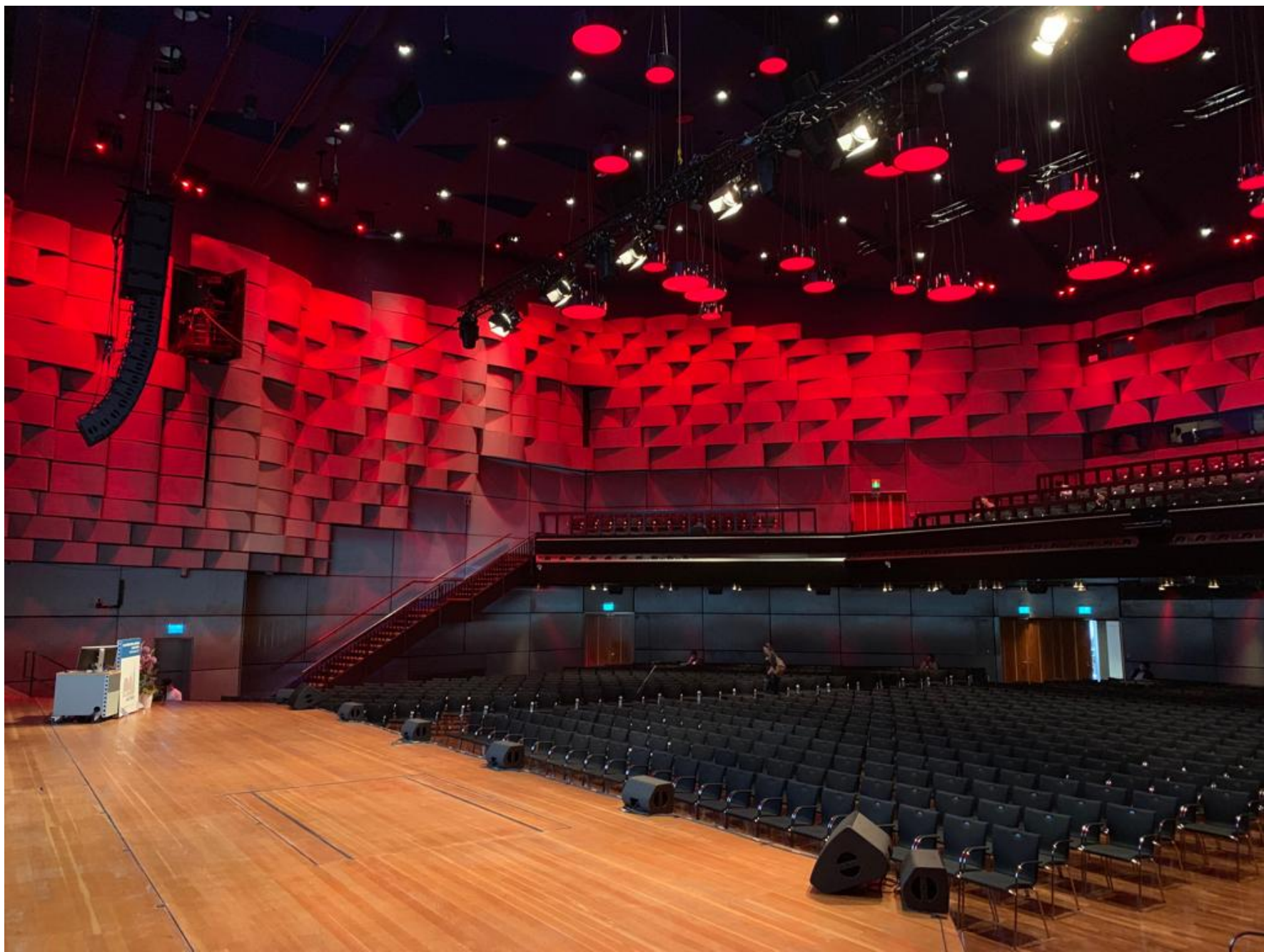
- All our life happens (mostly) in closed-space environments
- We hear not only the source signal but also its reflections
- Multiple propagation paths in a sound field



Aachen Eurogress center







What is Room Acoustics?

- All aspects of behaviour of sound in a room
- Good knowledge on the type of room
 - Dimensions
 - Materials properties
 - Target use: speech, music, live performance, video projection ...
 - Capacity (How many people)
 - ...

» **Acoustic design parameters**



What is Room Acoustics?

- Parameters, measurable and predictable which correlate with subjective perception
- RT is still an important parameters BUT not only...



Significance of room acoustics

- Room acoustical design
 - Design of sound reflections
 - Design of sound absorption
 - Design of the shape and geometry of the space
- Room acoustical design \neq maximizing the amount of sound absorbing material
 - E.g. in a lecture hall the performer must be able to speak without restraining ones voice and so that the audience can distinguish what is being said

Need for both sound absorbing and reflecting surfaces!

- Successful room acoustics is, thus, a combination of the geometry of the space and the absorptive and reflective properties of materials



Examples of design goals

- Movie theater
 - Hearing the sound track in the way the movie makers have intended it to be heard
- Concert hall
 - Good spatial impression (sound surrounds the listener), sense of intimacy, "warm" sound color, adequate clarity, etc.
- Restaurant
 - Peaceful acoustical environment (communication from short distance)



Examples of design goals

- Open plan office
 - Speech sound and other noise disrupts concentration and provides no speech privacy between work places
- Factory
 - Noise level may cause hearing damage,
 - » design of effective absorption and noise blocking screens



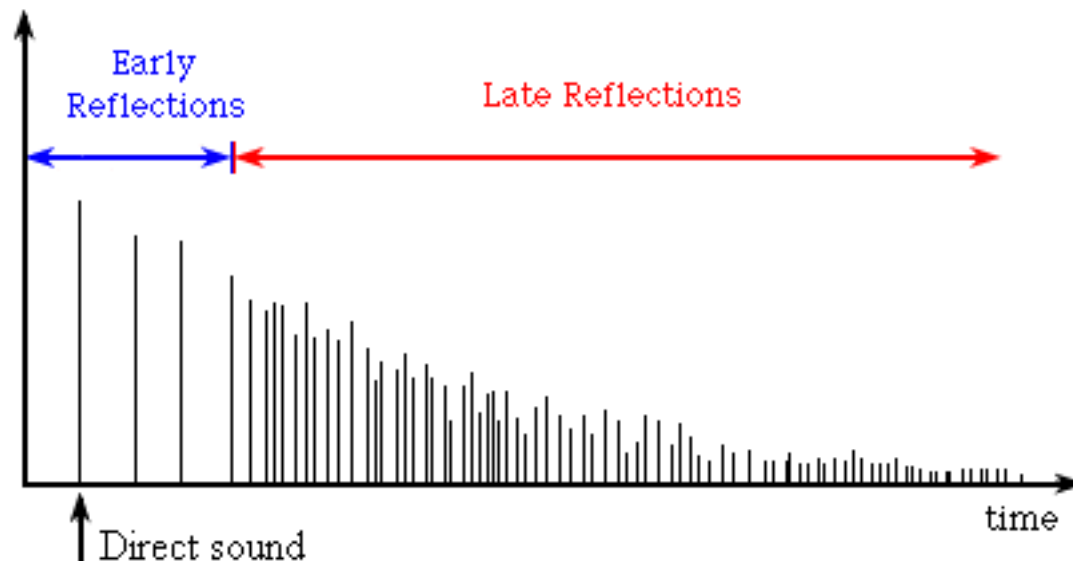
Parameters: Quality criteria

- RT and/or **sound level reduction** by distance from source may be sufficient in an industrial / working space
- More parameters must be used in concert hall
- ISO3382 standard
 - All parameters can be measured
 - All parameters are frequency-dependent
 - Based on impulse response measurements



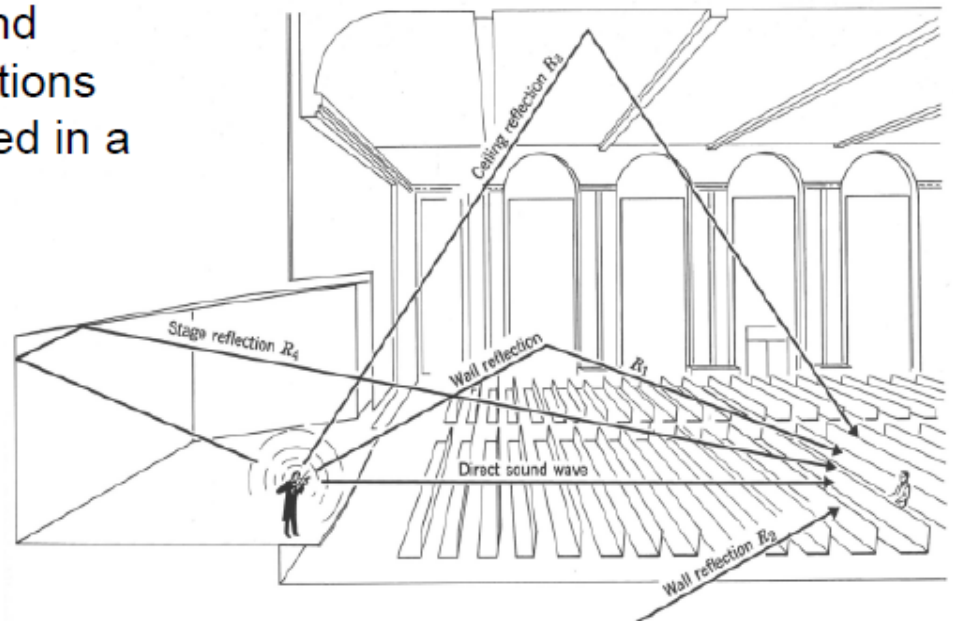
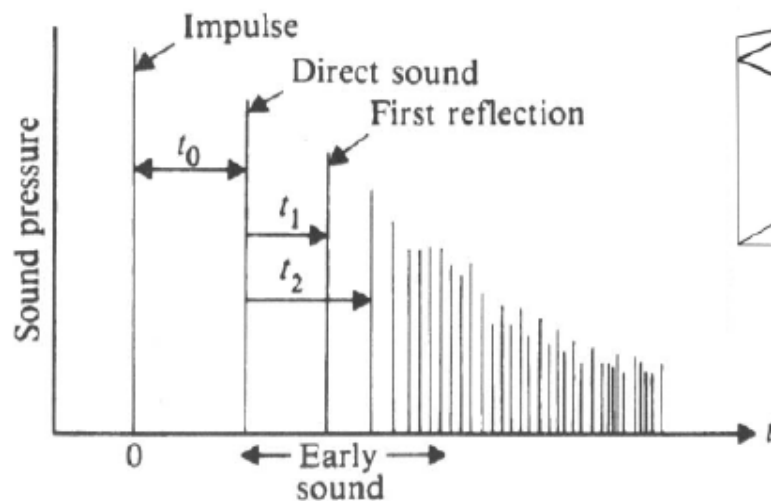
Parameters: Impulse Response

- Pulse is produced at zero time
- Direct arrival (earliest and strongest)
- Early reflections (up to 80 ms, distinct)
- Late reflections (high density)
- Late part is a reverberation in a common sense



Sound field in a room

Direct sound, early reflections and reverberant sound and their relations determine how sound is perceived in a space



Parameters : Early and Late Reflections

- Early reflections:
 - Strong and distinct
 - Provide spatial information
 - Should be modelled accurately
- Late reverberation:
 - Low intensity and high density of reflections
 - Provide room information
 - No longer depends on source position (diffuse field)
 - Can be modelled statistically

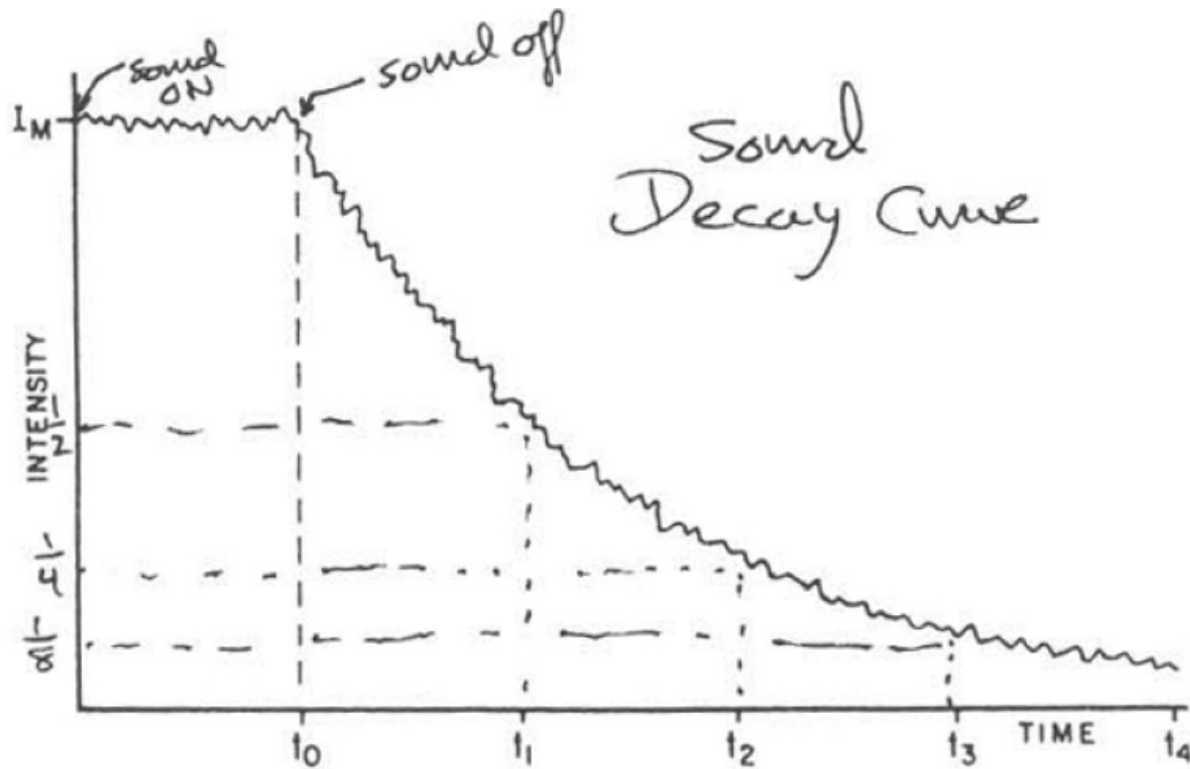


Parameters: operation specific

- Speech or music design:
 - Give a balanced set in time of the early reflections onto the audience
 - Reflections following the direct within a time span circa
 - » 50ms → Strength of the direct sound
 - But if longer delay: **Precedence** effect or Hass Effect
- Music:
 - Directional distribution is critical for listener
 - **Spaciousness** of the sound field
 - Laterals reflections are just as important as reflections from ceiling



Parameters: Reverberation time RT



Parameters: Reverberation time RT60

- The time needed for the Impulse Response to drop down 60 dB
- Alternatives T30, T20

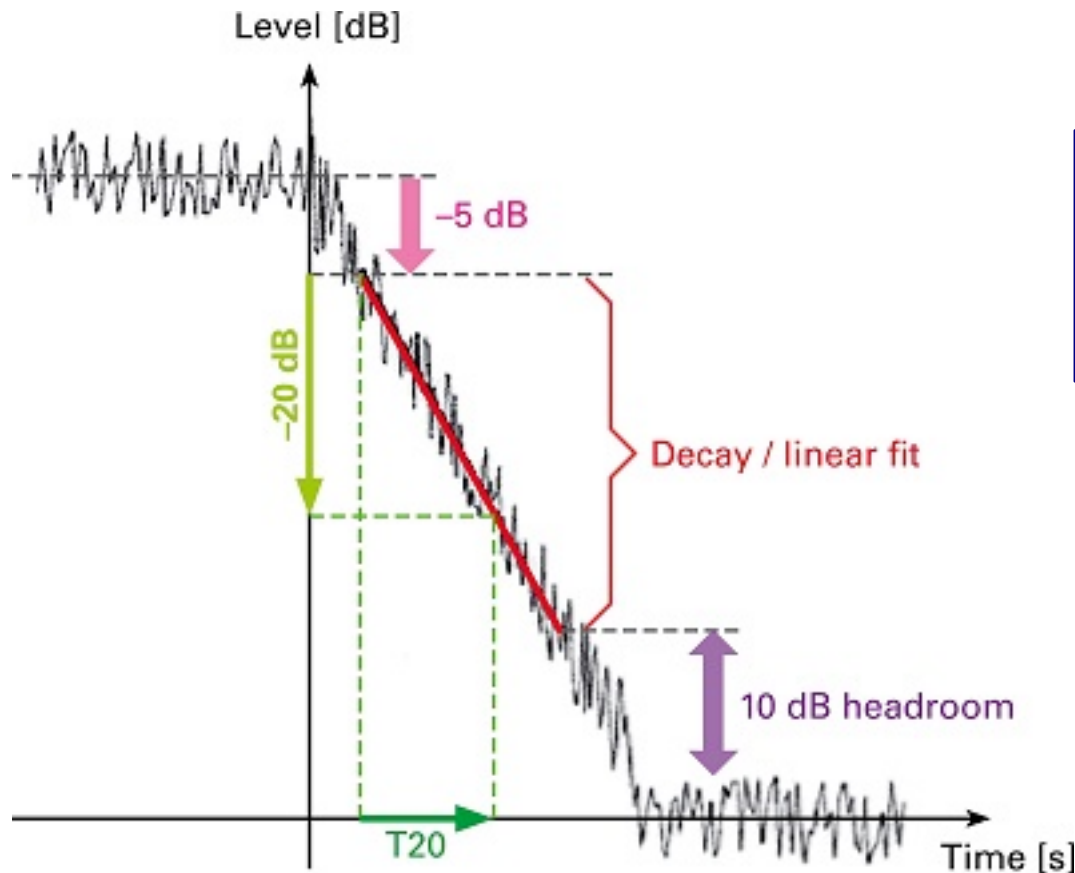
$$\text{Reverberation Time, } T = T_{60} = 0.049 \left(\frac{V \left(ft^3 \right)}{A \left(ft^2 \right)} \right) = 0.161 \left(\frac{V \left(m^3 \right)}{A \left(m^2 \right)} \right) \text{ seconds}$$

= time for sound to decay to 10^{-6} of its original intensity.

If the room has NO holes in it, the area A physically represents the effective area of the room that behaves as if it were a hole, due to sound absorption.



Reverberation time – Alternatives of RT/T60



T20 or T30 calculating a 20 or 30 dB drop instead if there is not enough information in the impulse response.

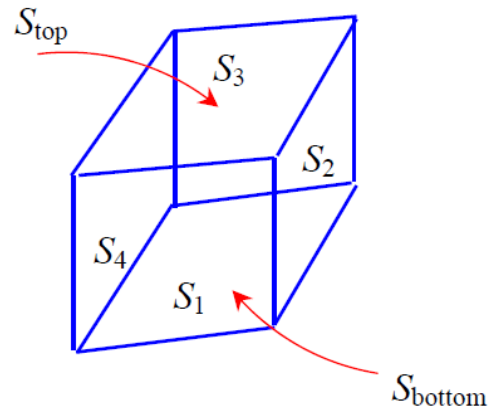
Source: <https://www.wikiwand.com/en/Reverberation>



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Parameters: Reverberation time RT60

Suppose a room with volume V has a surface area S made up of same material on all 6 sides:



Total surface area of room S :

$$S = \overbrace{S_1 + S_2 + S_3 + S_4}^{\text{area of sides}} + \overbrace{S_{\text{top}} + S_{\text{bottom}}}^{\text{area of top and bottom}}$$



Parameters: Reverberation time RT60

$$A = aS$$

$$a \equiv \frac{A}{S}$$

$a \equiv$ absorption coefficient, $0 \leq a \leq 1$

$a = 0 \Rightarrow$ **no** sound absorption (no “hole”, *i.e.* $A = 0$)

$a = 1 \Rightarrow$ **total** sound absorption (“hole” = room area, *i.e.* $A = S$!!!)



Parameters: Reverberation time RT60

For a more complicated/realistic room:

$$A = A_1 + A_2 + A_3 + A_4 + \dots A_N = \sum_{n=1}^N A_n$$
$$= a_1 S_1 + a_2 S_2 + a_3 S_3 + a_4 S_4 + \dots a_N S_N = \sum_{n=1}^N a_n S_n$$

for N objects (surfaces) in room.

The “Optimum” Reverberation Time:

- * If reverberation time is too short, room sounds “dead”
- * If reverberation time is too long, room sounds muddled/obscured

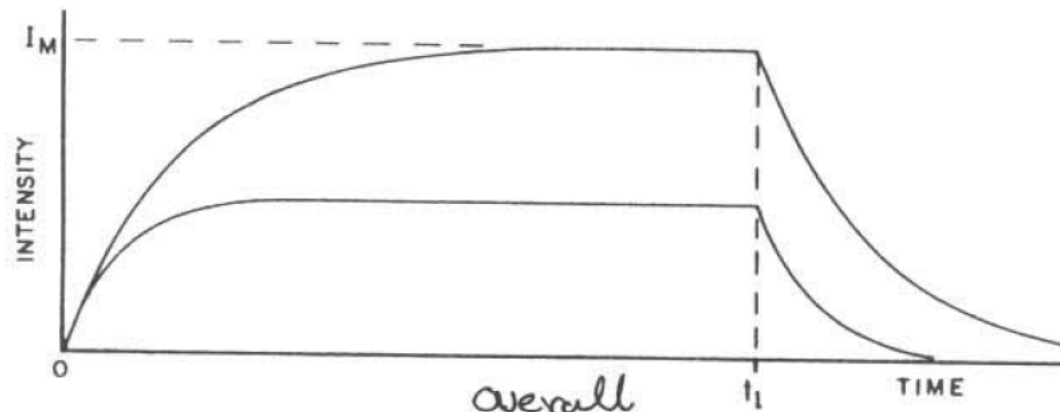


FIG. 4. Buildup and decay of sound intensity in an auditorium when a source of steady sound is present.

Parameters: Optimum RT60

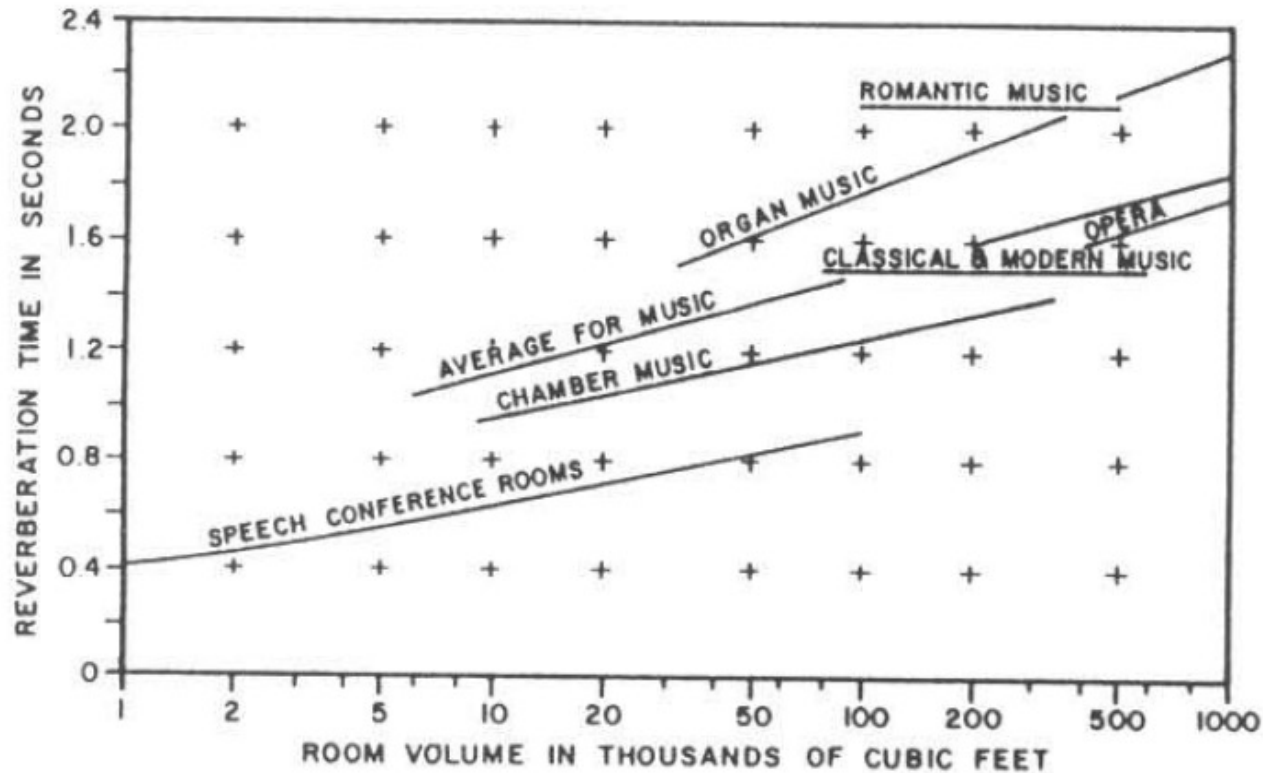


FIG. 5. Optimum reverberation time for auditoriums of various sizes and functions at a frequency of 500 hertz.



Parameters: EDT

- EDT : early decay time
 - From the first 10dB of decay



Parameters: Speech intelligibility

$$D_{50} \equiv 100 \times \left[\frac{\int_{t=0}^{t=50ms} p^2(t) dt}{\int_{t=0}^{t=\infty} p^2(t) dt} \right] (\%)$$



Parameters: Speech Clarity C50

- Balance between early (first 50ms) and late arriving sound energy.

A related statistic is speech Clarity, C_{50} defined as:

$$C_{50} \equiv 10 \log_{10} \left(\frac{\int_{t=0}^{t=50ms} p^2(t) dt}{\int_{t=0}^{t=\infty} p^2(t) dt - \int_{t=0}^{t=50ms} p^2(t) dt} \right) (dB)$$

For > 80% syllable intelligibility, a clarity of $C_{50} > -2dB$ is required, and is considered the minimum admissible limit for good speech intelligibility.



Parameters: Music Clarity C80

Music Clarity, C_{80} defined as:

$$C_{80} \equiv 10 \log_{10} \left(\frac{\int_{t=0}^{t=80ms} p^2(t) dt}{\int_{t=0}^{t=\infty} p^2(t) dt - \int_{t=0}^{t=80ms} p^2(t) dt} \right) (dB)$$



Parameters: Center Time

Another statistic is the Center Time $\langle t_s \rangle$, the mean/average time associated with a sound impulse, defined as:

$$\langle t_s \rangle \equiv \left[\frac{\int_{t=0}^{t=\infty} t \cdot p^2(t) dt}{\int_{t=0}^{t=\infty} p^2(t) dt} \right]$$



Parameters: Syllable Intelligibility

The {subjective} mean/average syllable intelligibility $\langle V_s \rangle$ is related to the center time $\langle t_s \rangle$ by:

$$\boxed{\langle V_s \rangle \equiv 96 \cdot \left(1 - 10^{-5} \langle t_s \rangle^2\right) \quad (\%)} \quad n.b. \ \langle t_s \rangle \text{ in } msec \text{ time units, here.}$$

For mean/average syllable intelligibility $\langle V_s \rangle > 80\%$, a center time of $\langle t_s \rangle \leq 130 \text{ msec}$ is required. If the center time is measured vs. octave bands center frequencies, then for speech one wants $\langle t_s(f_{ctr}) \rangle \leq 60 - 80 \text{ msec}$ for the 4 octave band centers at 500 Hz, 1000 Hz, 2000 Hz & 4000 Hz.



Parameters: Relation

- The relationship between C_{50} and D_{50} is then given by

$$C_{50} = 10 \cdot \lg \left(\frac{D_{50}}{1 - C_{50}} \right),$$



Parameters: Lateral energy fraction LF

- 8 microphones have to be used

$$LF = \int_{5\text{ms}}^{80\text{ms}} p_L^2(t) dt \bigg/ \int_0^{80\text{ms}} p^2(t) dt,$$

- LFC, contribution will be a function of cosine to this angle, more subjectively accurate

$$LFC = \int_{5\text{ms}}^{80\text{ms}} |p_L(t) \cdot p(t)| dt \bigg/ \int_0^{80\text{ms}} p^2(t) dt.$$



Parameters: Importance

- T30, EDT: Reverberation
 - $T60 = 2 * T30$
- D50: Clarity of speech
- C80: Clarity of music
- LF, LFC: Spatial impression
- Desired parameters depend on the purpose
 - Optimal T60 for speech: 40-60 ms
 - Optimal T60 for music: > 100 ms



Parameters: Critical Distance

- As you go further from source, direct sound level drops
- In contrast, reverberant sound level stays constant everywhere in the room
- Distance at which they are equal is the critical distance D_c

$$D_c = \left[\frac{S_e}{16\pi} \right]^{1/2}$$



Parameters: Summary

Parameter	Definition	JND
T_{30} , s	Reverberation time (energy drop from -5 to -35 dB)	5%
EDT, s	Early decay time (energy drop from 0 to -10 dB)	5%
D_{50} , %	Deutlichkeit (definition), ratio of early (0-50ms) to total energy	5%
C_{80} , dB	Clarity, ratio of early (0-80ms) to late (80ms-...) energy	1 dB
TS, ms	Center time, time of the 1 st moment of IR	10 ms
G, dB	Sound level at 10m from the omnidirectional source, referenced to free-field level (as if no room at all)	1 dB
LF, %	Ratio of early (5-80ms) energy weighted by $\cos^2(\text{lateral angle})$ (i.e., lateral energy) to total energy	5%
LFC, %	Ratio of early (5-80ms) energy weighted by $\cos(\text{lateral angle})$ (i.e., lateral energy) to total energy	5%
IACC	Interaural Cross Correlation Coefficient	0.2



Wavelength Influence

- Wavelength \ll object size:
 - Specular reflection (walls)
- Wavelength \gg object size:
 - No effect (coffee mug)
- Wavelength \sim object size:
 - Diffraction (table) (most complicated)



Thank you for your attention!

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