Physics of Musical Sound

Class 39

Read Chapter 23

Concert Hall Characteristics

- Intimacy
- Reverberation
- Apparent Source Width
- Listener Envelopment
- Clarity
- Warmth
- Loudness
- Acoustic Glare
- Brilliance
- Balance
- Blend
- Ensemble
- Immediacy of Response
- Texture
- Freedom from Echo
- Dynamic Range
- Tonal Quality
- Uniformity

Intimacy

- Sense that the music is being played in a small space. The recording industry uses Presence to mean the same quality.
- Largely determined by the initial-time-delay gap, the amount of time between the arrival of the direct sound and the first reflections. Ideal values fall between 15mS and 30mS.
- In general wider halls will have larger delays than narrow halls.

Reverberation

- The amount of time between the cessation of a note until the sound level has fallen by 60dB (enough to have disappeared).
- Can vary significantly as the number of people in the hall changes unless the seats are designed to absorb the same amount of sound as an average audience member.
- Halls lacking reverberation are described as dry or dead and are good for speech while those with longer reverberations are called live and are more appropriate for music.
- Hall can be reverberant in middle frequencies but lacking in treble or bass. Called warm is good bass support.

Clarity

- The ability to distinguish one sound from a another.
- In general the more reverberant a hall is, the less clear it will sound.
- Physically related to the Early Decay Time (EDT) the time for the sound to decay by 10dB (compared to the 60dB for the reverb. Time) and ratio of the energy that is reflected back early on (within 80mS) to that arriving later, C_{80}.
- Lots of early energy will make the sound clearer.

Spaciousness

- Apparent Source Width
  - Sense that the sound comes from a source that is wider than the visual source.
- Listener Envelopment
  - Sense that the sound comes from all round the listener.
- Both are related to the physical measurement of the Inter-Aural Cross-Correlation Coefficient (IACC), a measure of how different the sounds arriving at the two ears are.
- In general the lower the IACC is, the wider the ASW appears and the better the hall sounds.

Warmth

- The sense that the sound has a solid bass component.
- Described by the bass ratio (BR), the ratio of the low frequency reverb times to the upper frequency reverb times
  - $BR = \frac{RT_{125} + RT_{250}}{RT_{500} + RT_{1000}}$

Brilliance

- The opposite of warmth. Treble frequencies are prominent and decay slowly.
- Some wall and seat covering materials absorb more strongly at high frequencies and make the sound less brilliant.
- Wellin Hall's main flaw is a lack of brilliance caused by a somewhat short reverberation time at the highest frequencies.

Loudness

- A concert hall must make the sound seem reasonably loud to the listeners.
- Basically the sound needs to seem louder than it would if played outside.
- Obviously this varies from point to point in the hall (see Uniformity).
- Physically measured as G, the ration of the sound level in the hall to the level you would get in the open with the same source.

Acoustic Glare

- This is a strange problem produced by large flat, smooth surfaces that can reflect early sound to the audience.
- Sound becomes brittle or harsh in quality. It is called glare by analogy with the same effect in light.
- Cure is to break surfaces up or curve them.

Balance

- The relative audibility of different musical sources. E.g. soloist compared to orchestra, choir compared to orchestra, soloist compared to choir.
- A lot of this is under control of the conductor.
- Strongly reflective surfaces near stage can affect this as can putting the orchestra into a pit as is done for opera.

Blend

- Sounds from different instruments or from different sound sources need to arrive at the listener in a harmonious manner.
- The sonic characteristics of the different sounds should not be too different. E.g. you shouldn't have a significantly different ASW for one sound than for another.
- Again, depends on the design of the stage and on the sound reflecting surfaces close to the performers.

Ensemble

- The ability of the performers to play in unison--to start and end notes together.
- The performers must be able to hear each other clearly.
- Depends strongly on stage design.
- Sound reflecting surfaces near and around the stage must reflect a significant portion of the energy back to the stage so that the performers can hear each other.

Immediacy of Response

- This is to the performer what intimacy is to the audience.
- Related to the route that the early reflections take to reach the musicians ears.
- Want a very short initial time-delay gap for the performers.
- But, if too little sound comes back later on, having reflected from the hall, then the musicians may not be aware of the hall at all.

Texture

- A measure of the uniformity of the early reflections.
- Want the early reflections to arrive with a smooth distribution of delays.
- If there are significant bumps or dips in the sound level of the early reverberation then the hall will sound uneven.
- The best halls have a large number of early reflections that arrive uniformly, but not periodically, spaced and with similar strengths.

Freedom from Echo

- An echo is a single clear reflection that arrives with more than about 0.1s delay and is heard as a separate sound.
- Echo is extremely annoying to the audience.
- Echoes can come from ceilings that are extremely high or from rear walls that are flat or concave and a long distance from the stage.

Dynamic Range

- Number of decibels between the loudest sound that can be produced in the hall to the quietest sound that can be heard.
- Dominated by background noise.
- In an ideal hall should be dominated by the sound that the audience makes.
- In a good modern hall it is often dominated by the air-handling system.
- Don't put a concert hall next to an airport!

Tonal Quality

- Beauty of tone, how faithfully does the sound heard by the listener match that produced by the performers.
- The hall should not add any extraneous sounds, rattles or resonances of decorations and furnishings for example.
- To strong a reflecting surface can produce a shift in the apparent location of the sound source which is also disconcerting.

Uniformity

- Sound should be the same in every seat in the house. Failing that, it should be as similar as possible.
- Overhanging balconies, funny recesses in the seating pattern, objectionable reflections in certain locations can all detract from the uniformity.

Good Values for Good Halls

- Reverberation Time (RT)
  - 1.8s-2.0s seems strongly preferred. Earlier music favors shorter reverb times (down to as low a 1.5s) and later, more romantic music favors the longer times.
  - Cathedral music is a special case. Some sacred choral works and a lot of organ works were written to be performed in huge stone buildings with reverberation times as long as 10s!
- Early Delay Time (EDT)
  - Quoted as 6x time to decay by 10dB.
  - Should be a little longer than RT, about 2.2s.

Good Values for Good Halls

- Spaciousness
  - 1-IACC should be fairly high. In Beranek's study the best halls had values about 0.7 while the poorer halls had values as low as 0.4
- Initial time-delay gap (t_1)
  - Varies from point to point within a hall. Near the center of the hall a value of 20mS or less seems adequate.
  - Values greater than 35mS generally mean significantly poorer halls.

Good Values for Good Halls

- Strength Factor (G_{mid})
  - Ratio (in dB) of the sound level in the mid-frequencies (500-1000Hz) to the level from the same source outside.
  - Values of about 5-6dB seem common in good halls.
  - This is less than a factor of two in loudness and only 2-3x larger than the just noticeable difference in amplitude.
  - Bass Ratio (BR)
    - Range 1.1-1.45
    - Higher values are preferred in halls with shorted RTs.

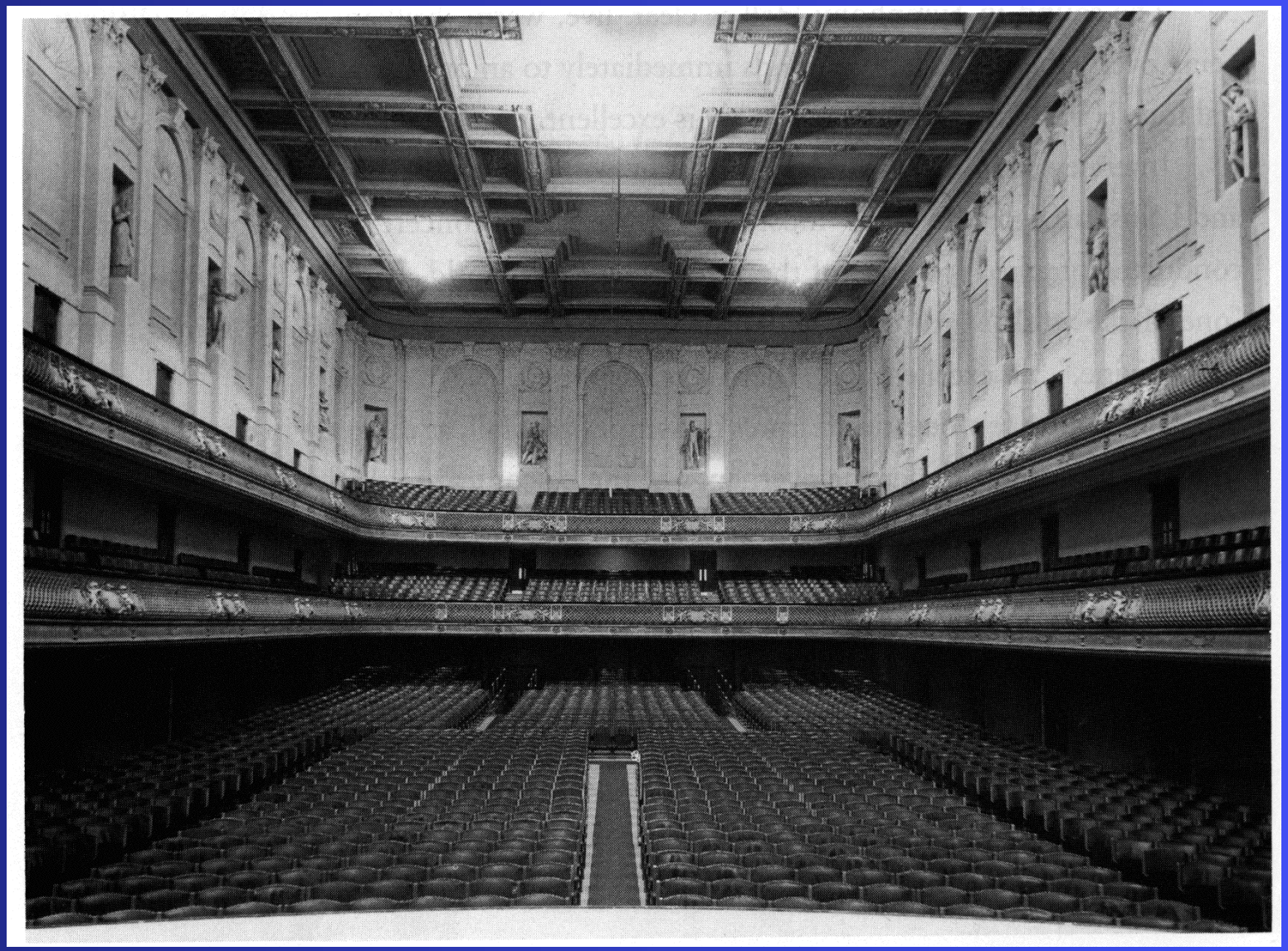
Good Halls from Beranek

CITY AND NAME OF HALL	RT Occ. sec	EDT Unocc.	BR Occ.	No. of Seats	Cubic Vol. cu m
Category A+ "Superior":					
Amsterdam, Concertgebouw	2.0	2.6	1.08	2,037	18,780
Boston, Symphony Hall	1.85	2.4	1.03	2,625	18,750
Vienna, Gr. Musikvereinssaal	2.0	3.0	1.11	1,680	15,000
Category A "Excellent":					
Basel, Stadt-Casino	1.8	2.2	1.17	1,448	10,500
Berlin, Konzerthaus (Schauspielhaus)	2.05	2.4	1.23	1,575	15,000
Cardiff, Wales, St. David's Hall	1.95	2.1	0.96	1,952	22,000
New York, Carnegie Hall	1.8	-	1.14	2,804	24,270
Tokyo, Hamarikyu Asahi	1.7	1.8	0.94	552	5,800
Zurich, Grosser Tonhallesaal	2.05	3.1	1.23	1,546	11,400
Average of Categories A+ & A:	**1.9**	**2.45**	**1.10**	**1,802**	**15,722**
Median of Categories A+ & A:	**1.95**	**2.4**	**1.11**	**1,680**	**15,000**
Category B+ "Good to Excellent":					
Number of halls:	35				
Average volume:				**19,200 m³ (680,000 ft³)**	
Average seat count:				**2,320**	
Average BR			**1.08**		
Average EDT		**2.0 sec**			
Average RT:	**1.7 sec**				
Category B "Good":					
Chicago, Orchestra Hall*	1.25	-	1.15	2,582	18,000
Edmonton, Alberta Jubilee Hall	1.4	1.4	0.99	2,678	21,500
Montreal, Salle Wilfrid-Pelletier*	1.65	1.9	1.21	2,982	26,500
San Francisco, Davies Hall*	1.85	2.15	1.11	2,743	24,070
Tel Aviv, Mann Auditorium	1.55	1.7	0.98	2,715	21,240
Category C+ "Fair to Good":					
Bloomington, Univ. Auditorium	1.4	-	1.12	3,760	26,900
Buffalo, Kleinhans Music Hall*	1.3	1.6	1.28	2,839	18,240
London, Barbican Concert Hall*	1.75	1.9	1.07	2,026	17,750
Average of Categories B & C+:	**1.5**	**1.8**	**1.12**	**2,791**	**21,422**
Median of Categories B & C+:	**1.5**	**1.8**	**1.14**	**2,729**	**21,370**
Category C "Fair":					
London, Royal Albert Hall	2.4	2.6	1.13	5,080	86,650

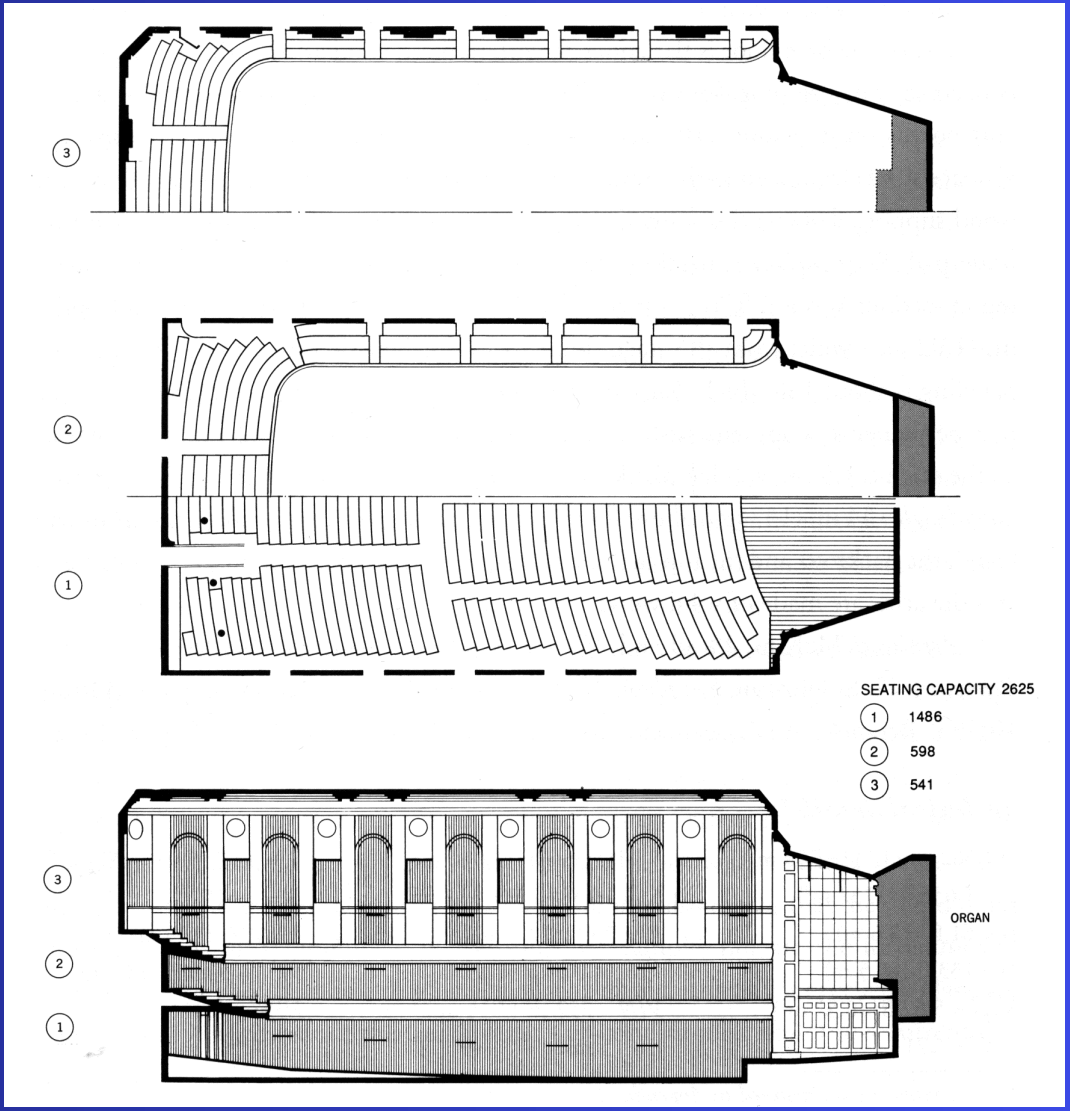
*Before renovations either recently completed, underway or in planning to improve acoustics.

Boston Symphony Hall

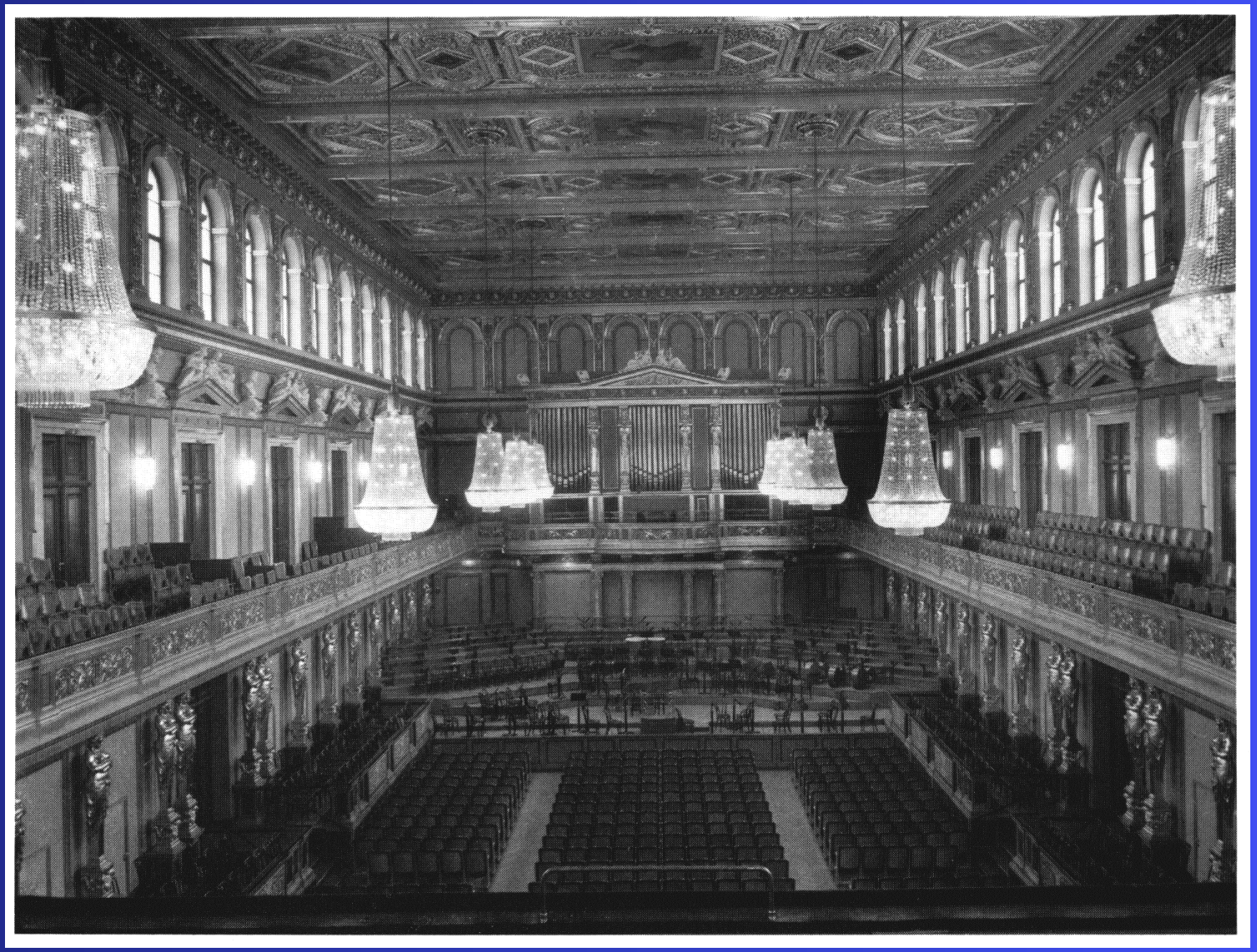
Boston Symphony Hall



Boston Symphony Hall



Vienna Musikvereinssaal



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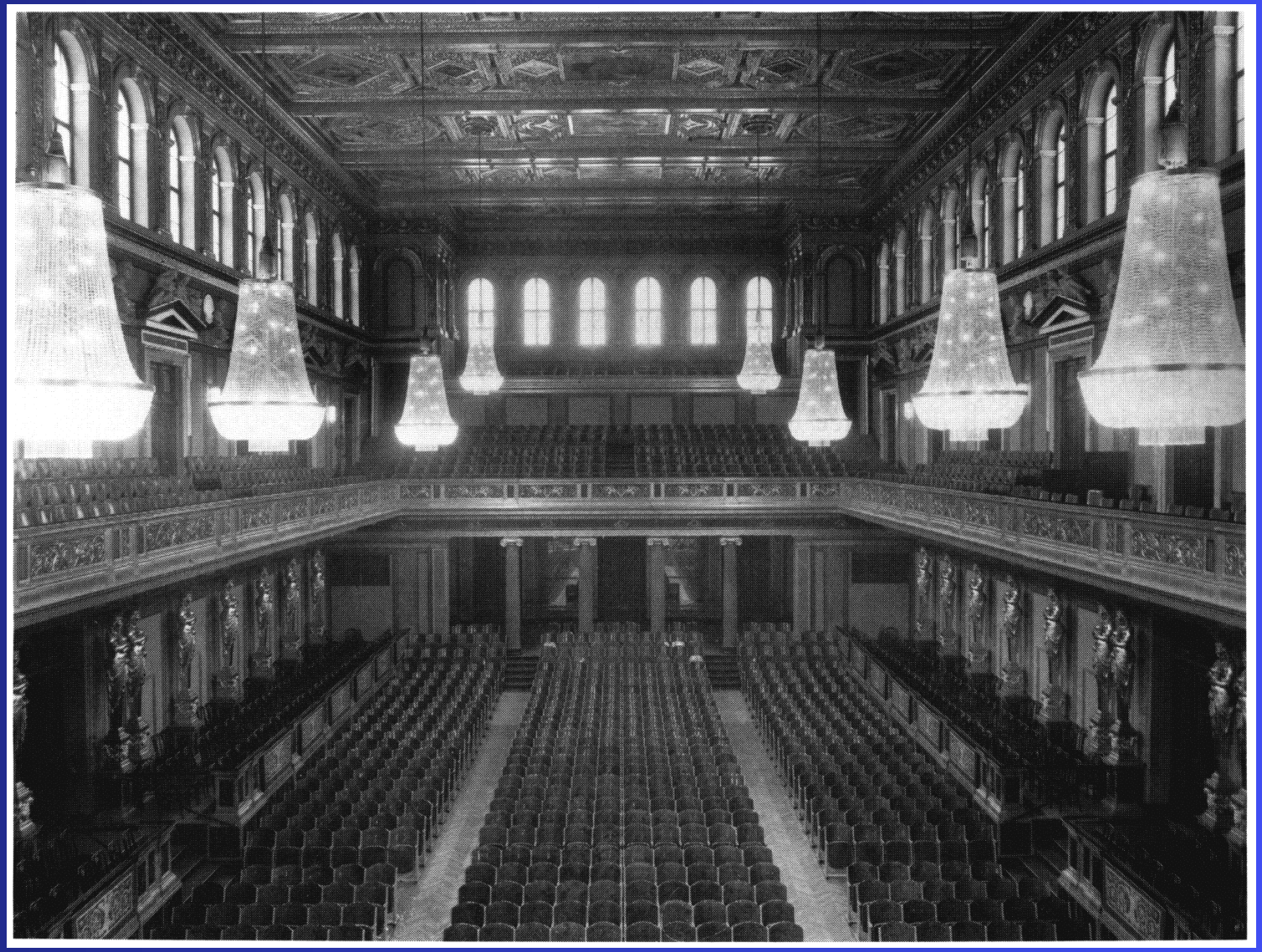

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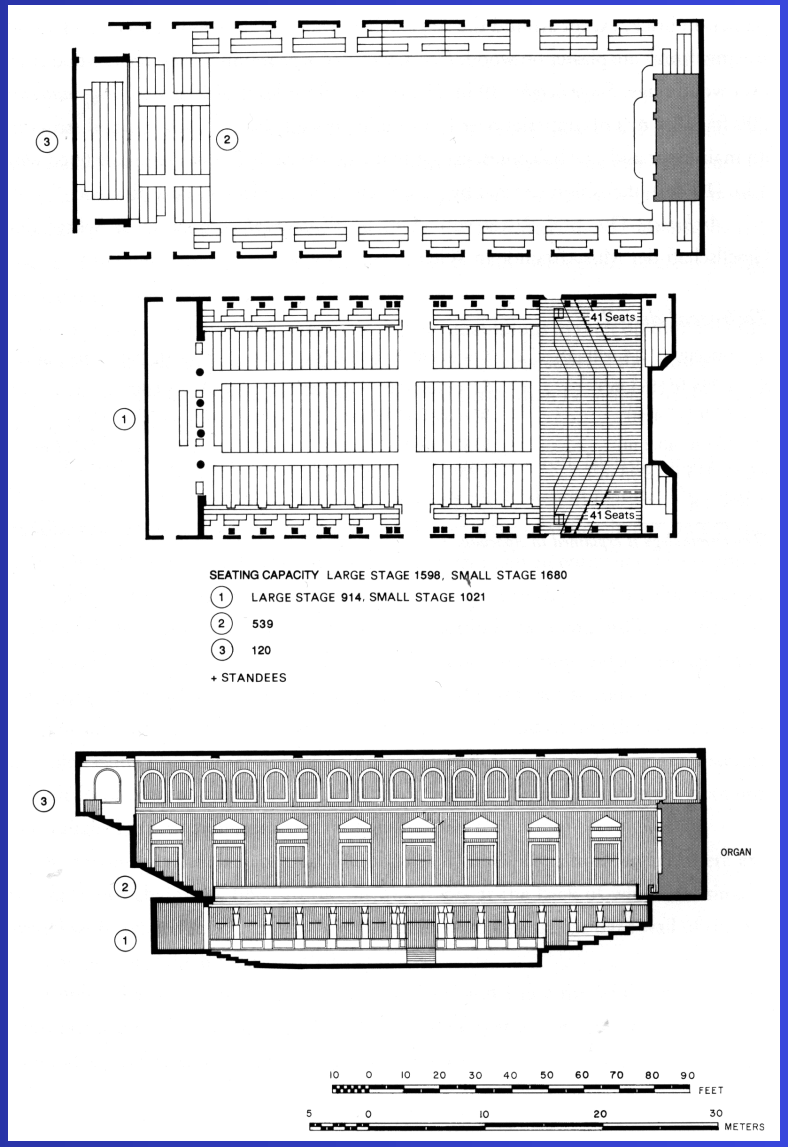

Koussevitzky Music Shed

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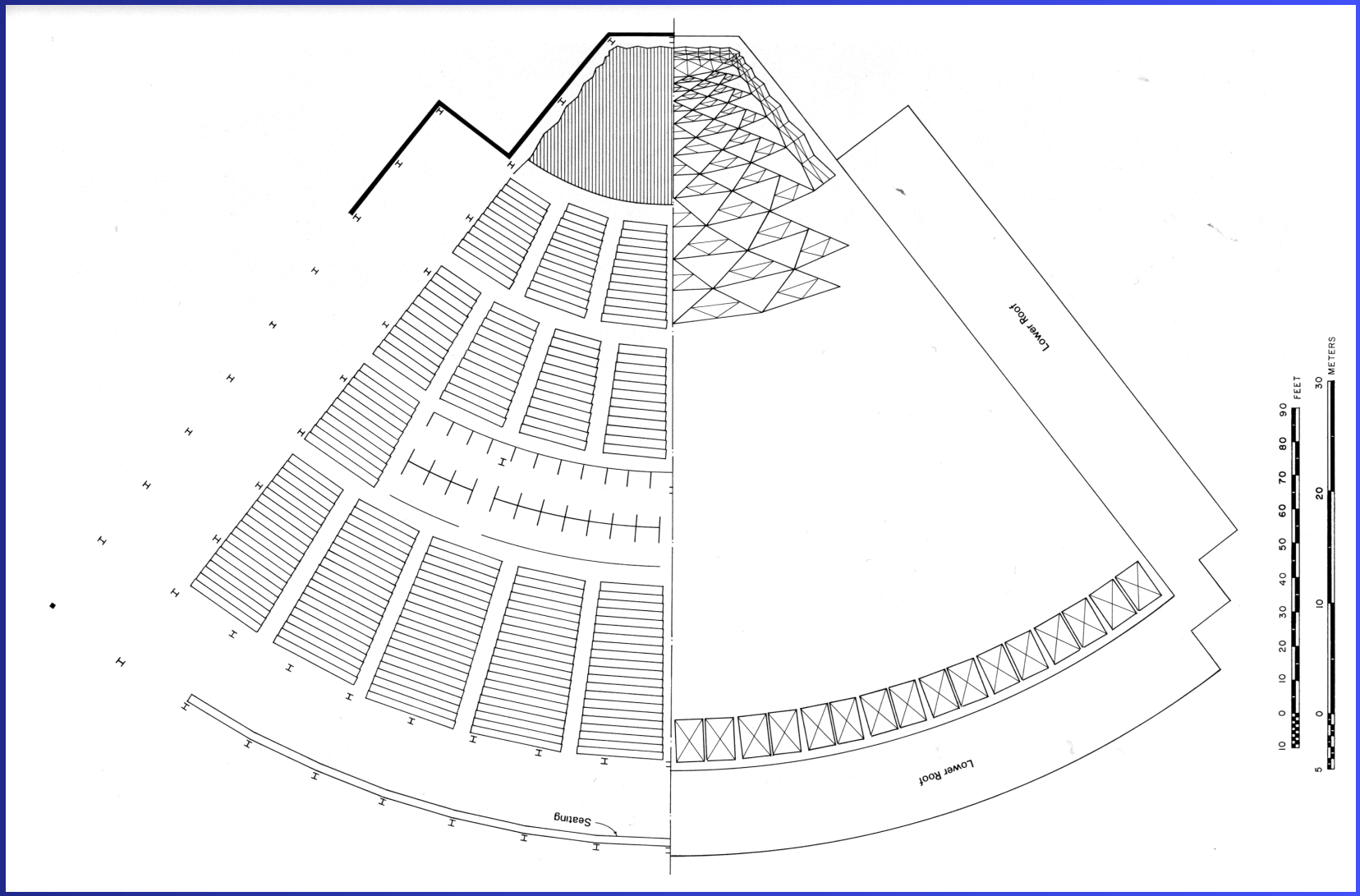

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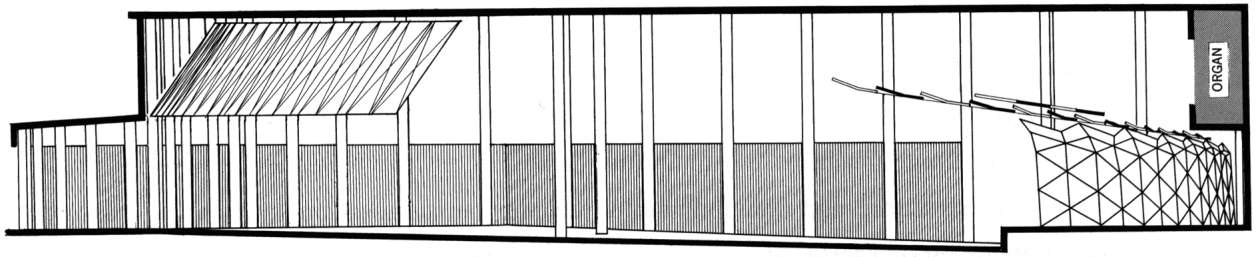

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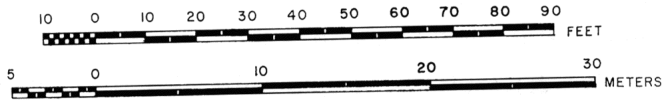

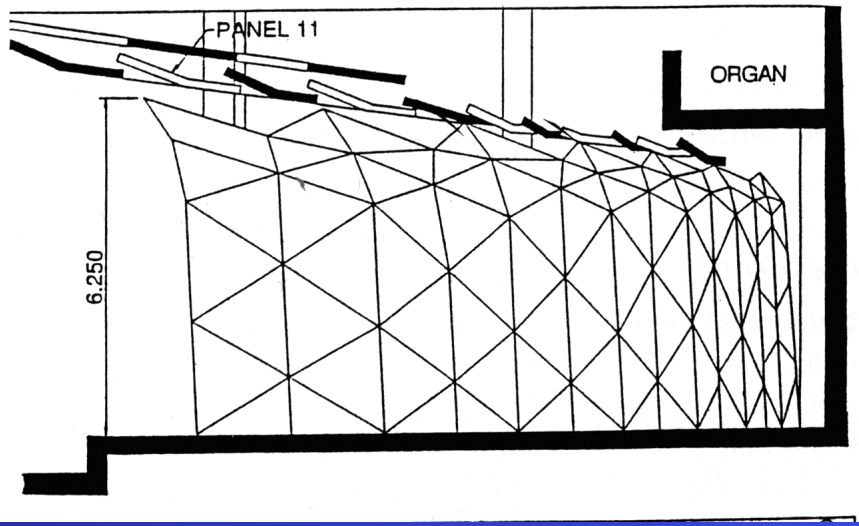

Royal Albert Hall

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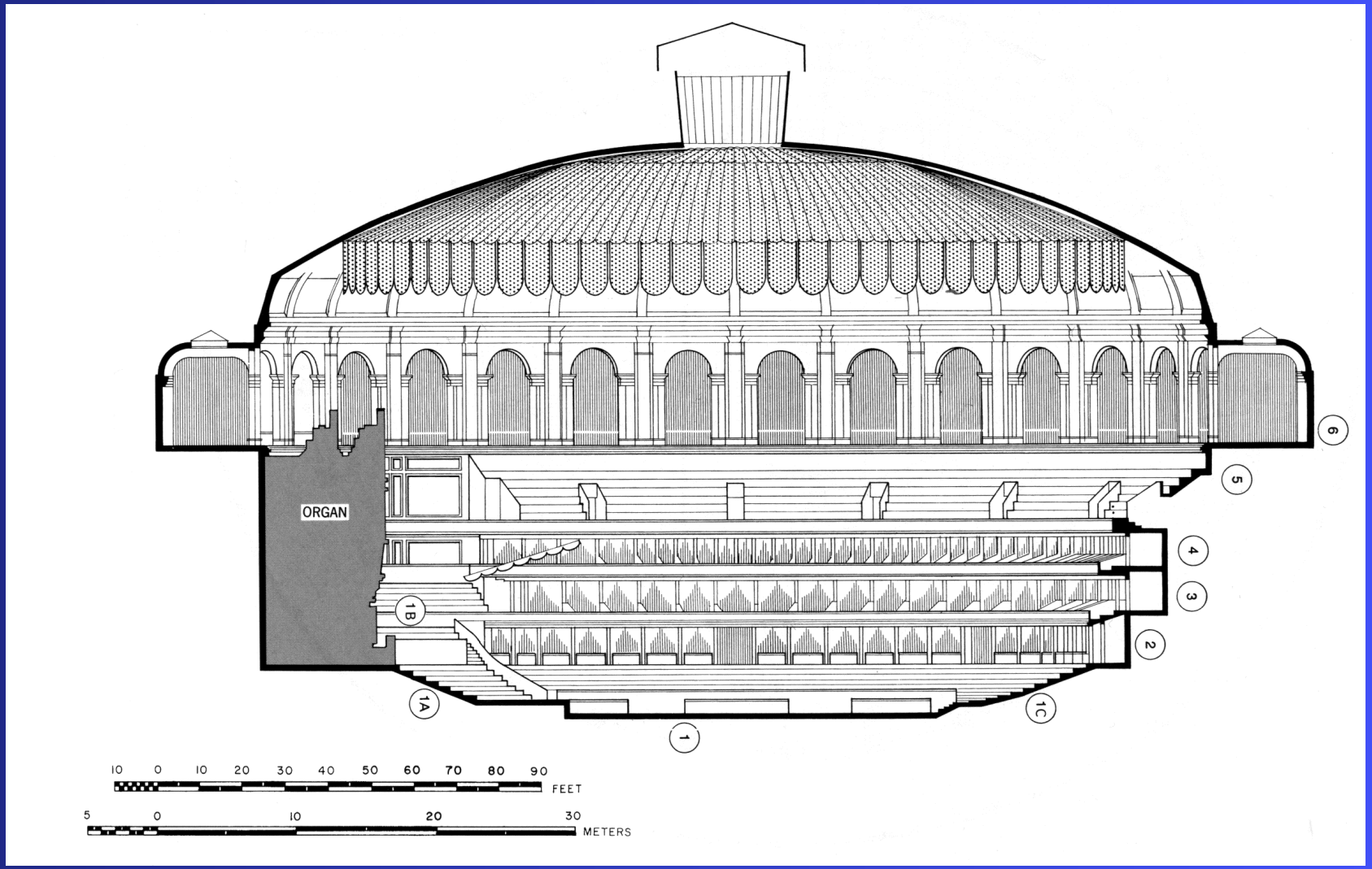

Royal Albert Hall