



# ACOUSTICAL SUITABILITY OF HISTORIC SPACES AS VENUES FOR MODERN-DAY EVENTS

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- Introduction
- Investigated spaces with measurement results and evaluation
- Conclusions

# Introduction

- Dubrovnik - an independent republic based on maritime trade, particularly during the 15<sup>th</sup> and 16<sup>th</sup> century
- UNESCO World Heritage Site:
- “The 'Pearl of the Adriatic', situated on the Dalmatian coast, became an important Mediterranean naval power from the 13<sup>th</sup> century onwards. Although severely damaged by the earthquake of 1667, Dubrovnik managed to preserve its beautiful Gothic, Renaissance and Baroque churches, monasteries, palaces and fountains. Damaged again in the 1990s in armed conflict, it is now the focus of a major restoration program coordinated by UNESCO.



# Introduction

- diverse cultural program for visitors → Dubrovnik Summer Festival
- venues = historic spaces of great significance + modern-day buildings
- acoustical suitability of the venues for the foreseen applications
- 5 venues chosen for evaluation
- $RT_{60}$ ,  $EDT$ ,  $C_{50}$ ,  $C_{80}$ ,  $G$ ,  $LF_E$ ,  $BQI$ ,  $STI$ ,  $ITDG$  and  $V/N$

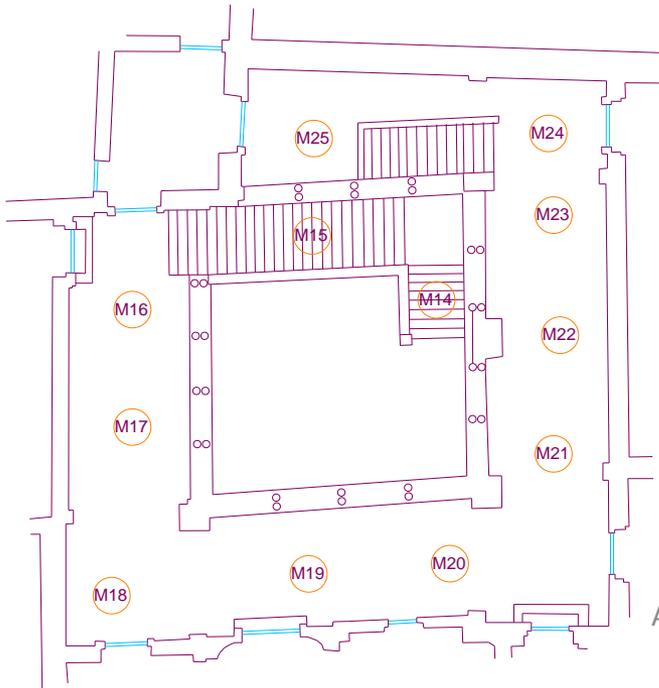
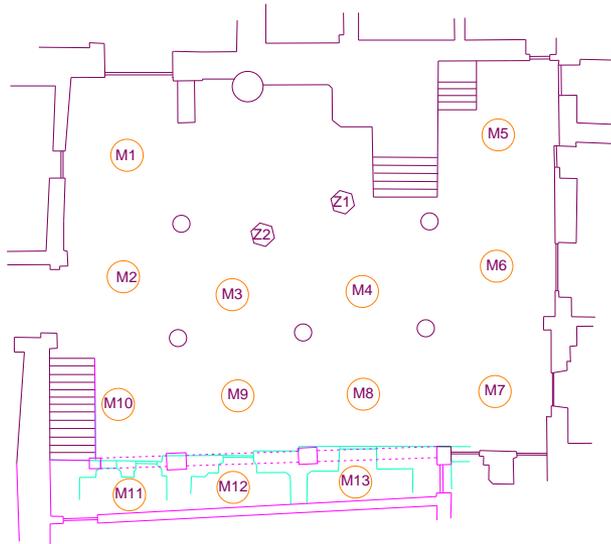


# Venues - the Rector's Palace

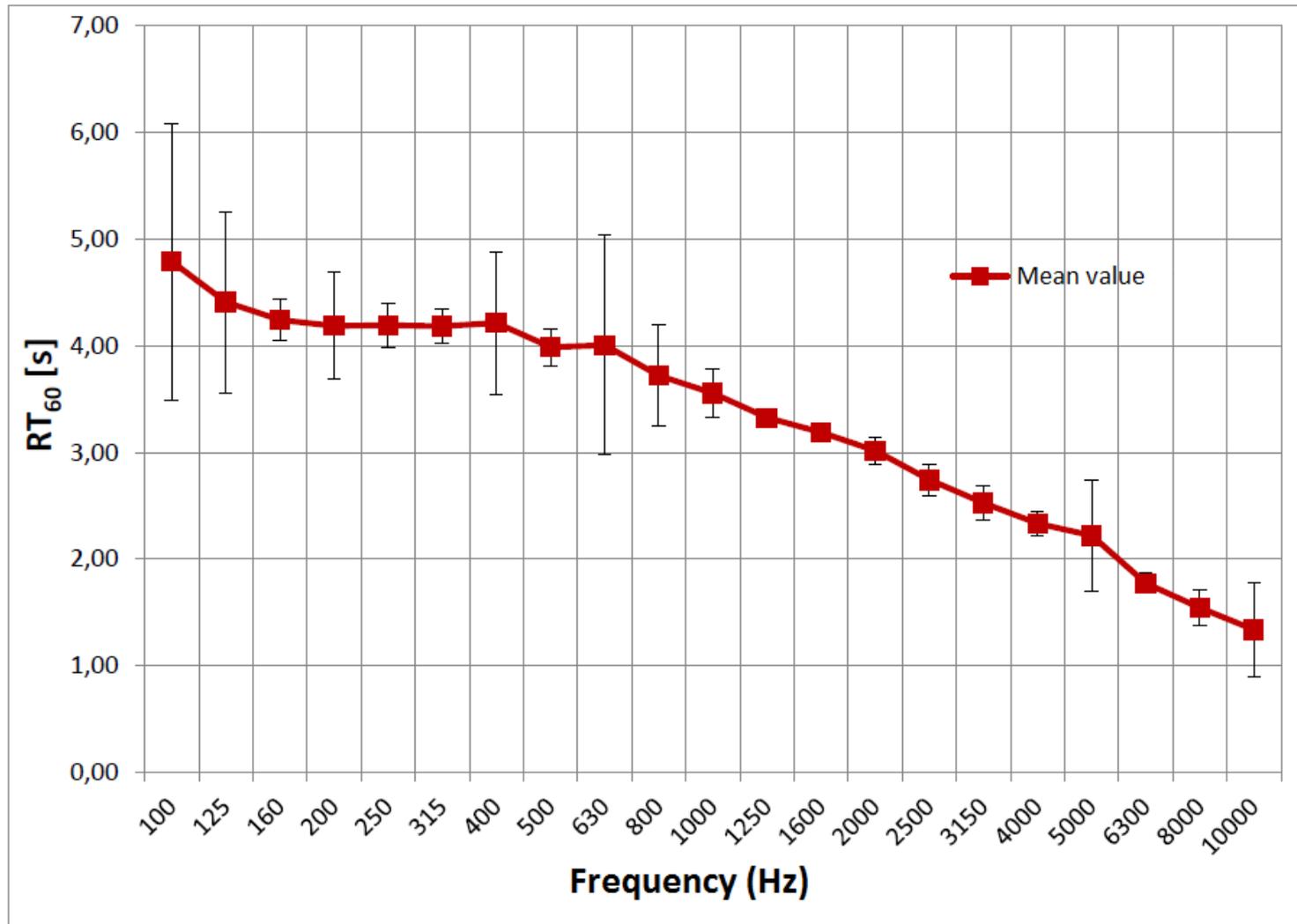
- 13<sup>th</sup> century building
- one of the most significant architectural monuments on Croatian coast
- atrium - classical and chamber music performances
- 300 seats - ground floor and balcony
- total volume = 2900 m<sup>3</sup>



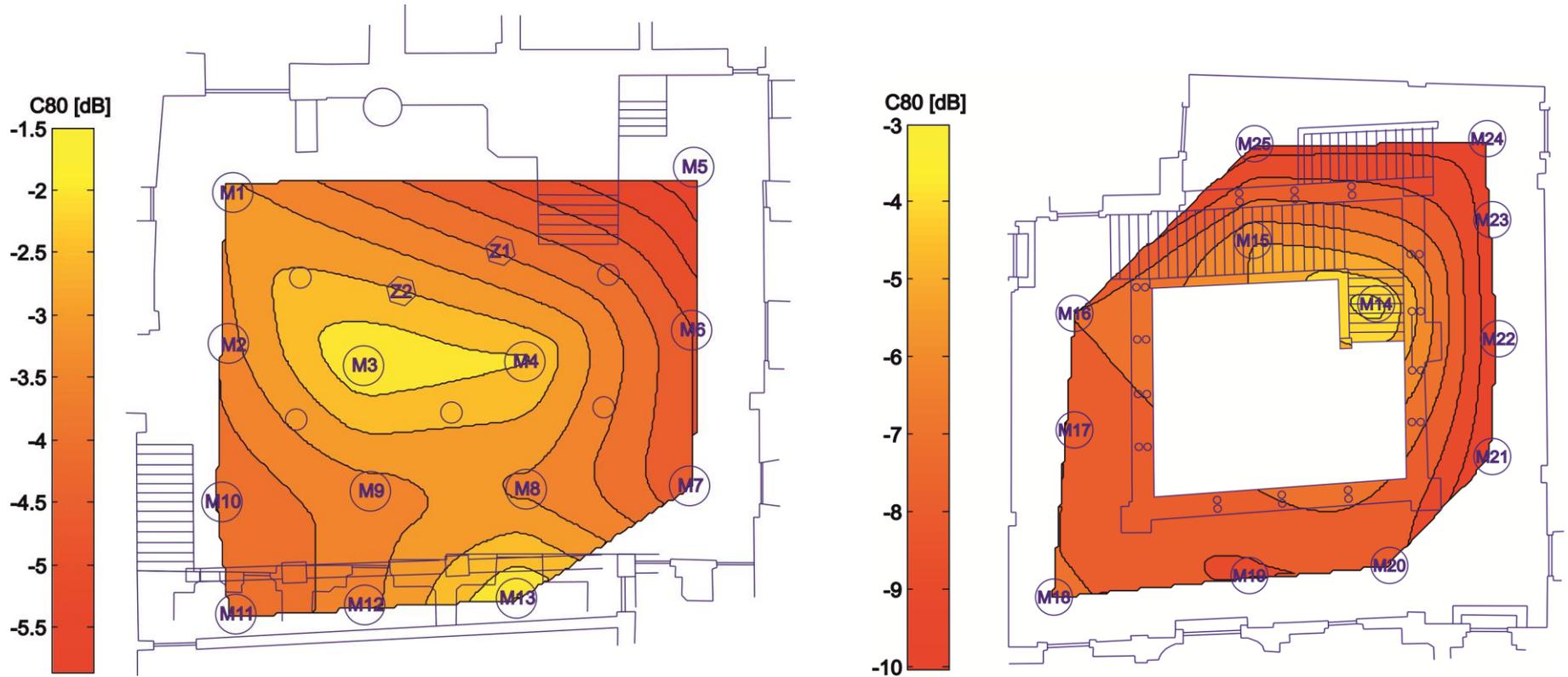
# Venues - the Rector's Palace



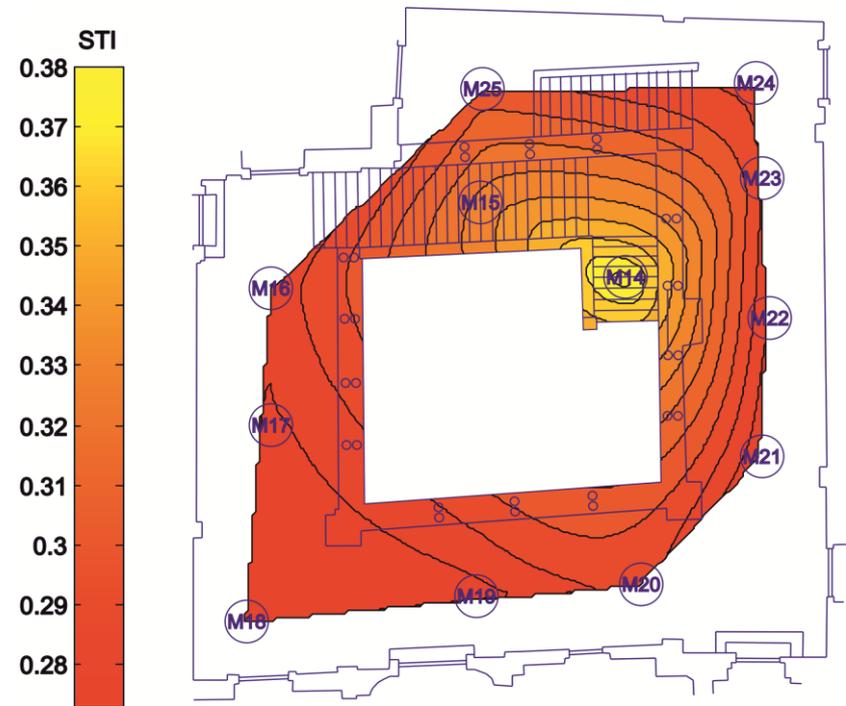
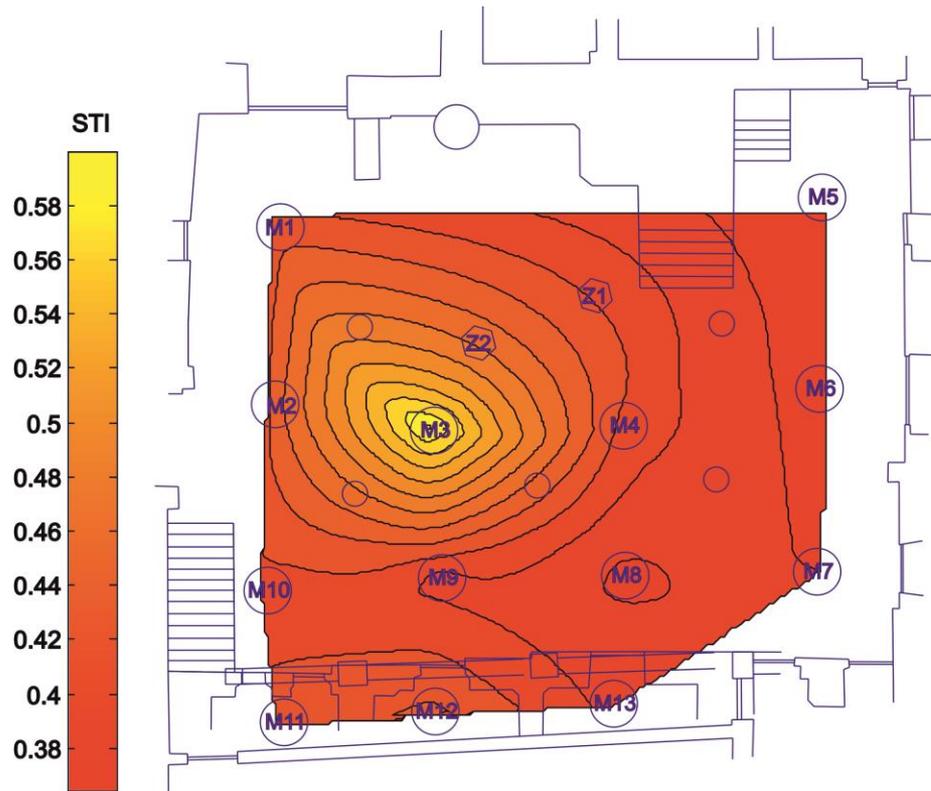
# Venues - the Rector's Palace



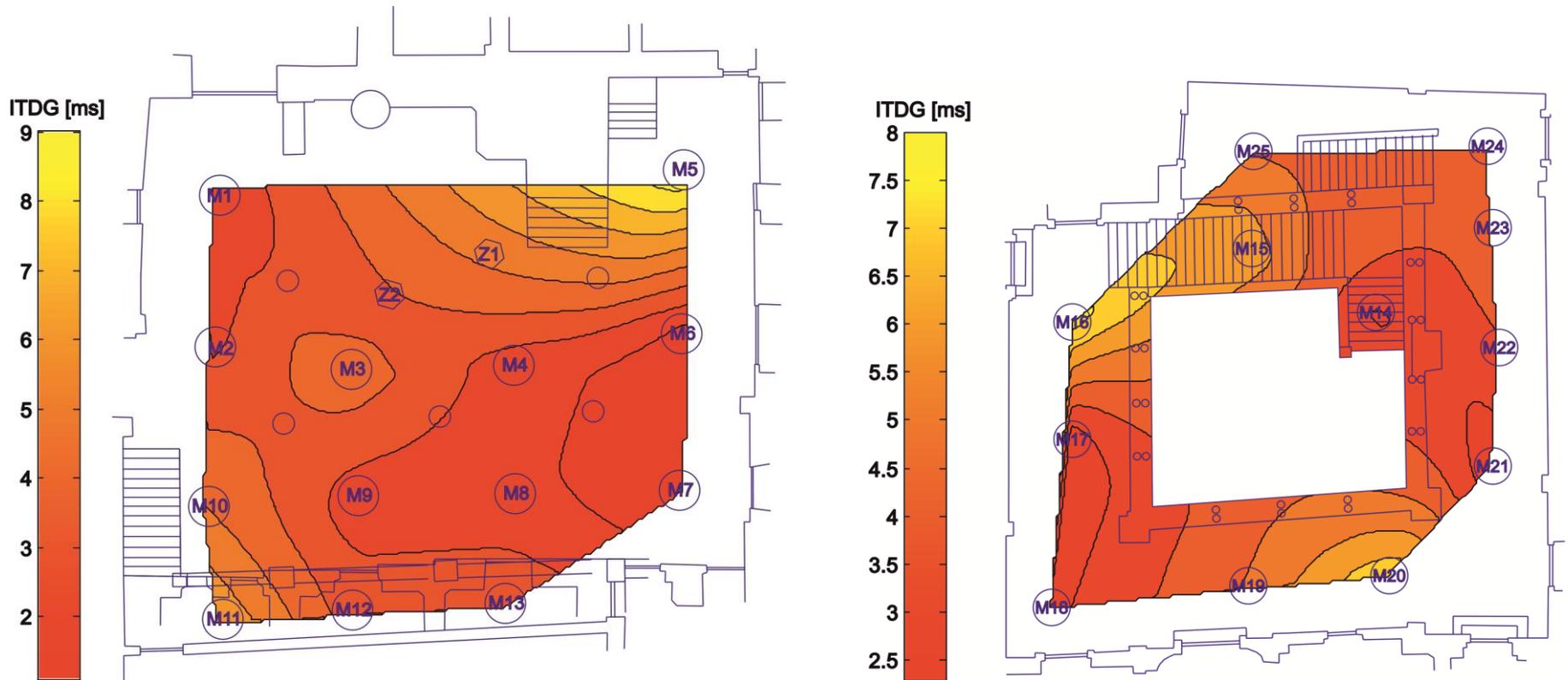
# Venues - the Rector's Palace



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- Evaluation according to:
  - HRN EN ISO 3382-1:2010 „Measurement of room acoustic parameters -- Part 1: Performance spaces “
  - L. Beranek: „Concert halls and opera houses: music, acoustics and architecture“, Springer-Verlag 2004.
  - D. Rossing: „Springer Handbook of Acoustics“, Springer Verlag, 2007.
  - M. Long: „Architectural Acoustics“, Academic Press, 2006.

# Venues - the Rector's Palace

Frequency averaged values on measuring locations for empty concert halls and multipurpose halls smaller than 25.000 m<sup>3</sup> according to the EN ISO 3382-1:2010 norm

Acoustical parameter	Frequency (Hz)	Typical values	Knežev dvor
Gain G, dB	500 – 1000	-2 dB to +10 dB	7 dB
EDT, s	500 – 1000	1,0 s to 3,0 s	3,72 s
Clarity C <sub>80</sub> , dB	500 – 1000	-5 dB to +5 dB	-5,5 dB
Definition D <sub>50</sub>	500 – 1000	0,3 to 0,7	0,15

# Venues - the Rector's Palace

Recommended averaged values of some acoustic parameters of empty concert halls for classical music (Rossing).

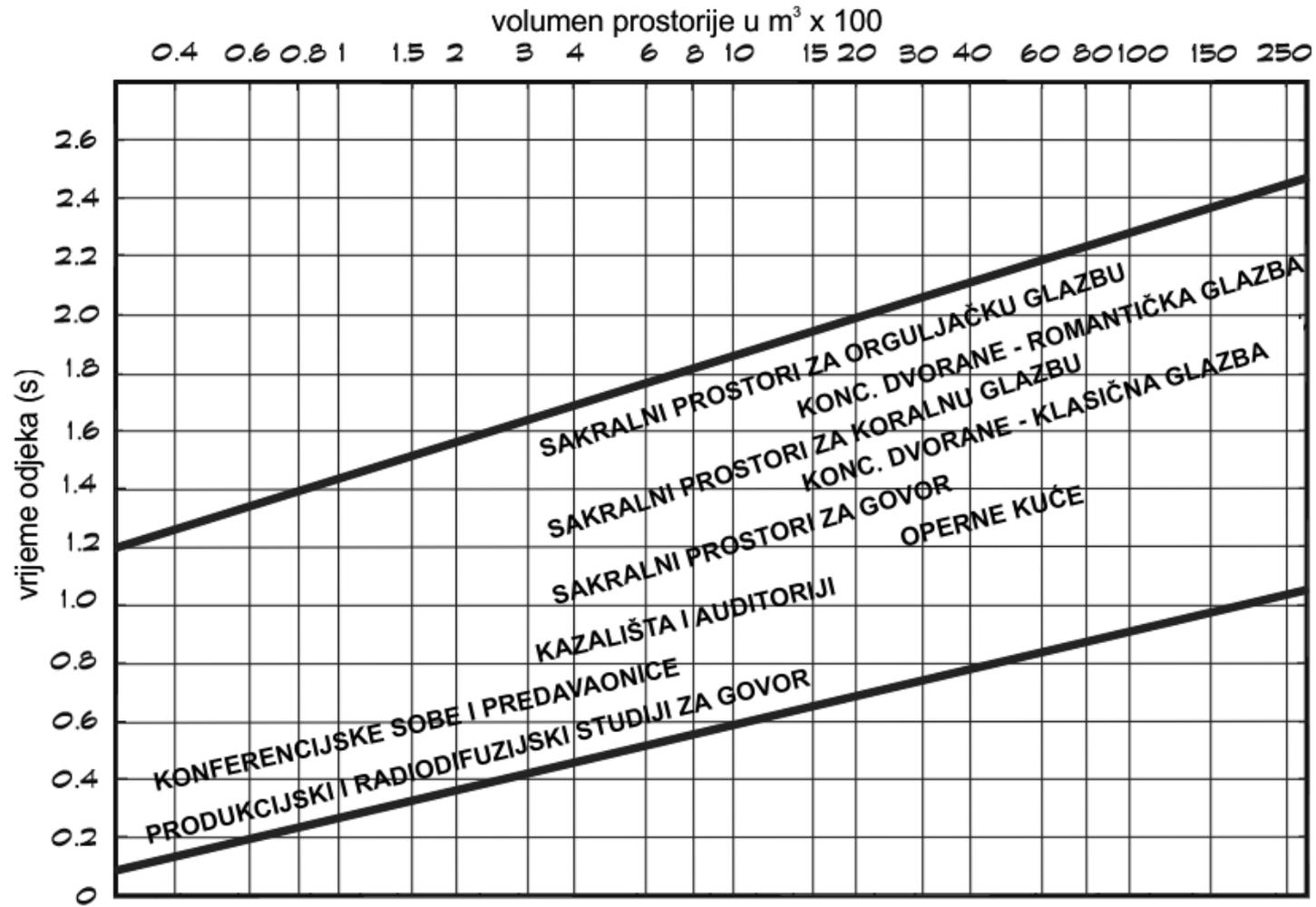
Parameter	Symbol	Chamber music	Symphonic music	Knežev dvor
Hall size	V/N	2.500 m <sup>3</sup> / 300 seats	25.000 m <sup>3</sup> / 2.000 seats	2.910 m <sup>3</sup> / 300 seats
Reverberation time	T	1,5 s	2,0 – 2,4 s	3,80 s
Early decay time	EDT	1,4 s	2,2 s	3,72 s
Gain	G	10 dB	3 dB	7,0 dB
Clarity	C	3 dB	-1 dB	-5,5 dB
Lateral energy fraction	LEF	0,15 – 0,20	0,20 – 0,25	0,20
Binaural quality index	1-IACC	0,6	0,7	0,74

# Venues - the Rector's Palace

Optimum values for some acoustic parameters of concert halls (Beranek).

Acoustical parameter	Purpose			
	symphonic music (over 1.400 seats)	chamber music (manje od 700 seats)	opera (preko 1.200 seats)	Knežev dvor
Reverberation time $RT_{60}$	1,8 – 2,1 s	1,6 – 1,8 s	1,4 – 1,6 s	3,80 s
Early Decay Time EDT	2,2 – 2,6 s	1,9 – 2,3 s	1,5 – 1,9	3,72 s
Binaural Quality Index BQI	0,65 – 0,71	0,7 – 0,76	0,6 – 0,71	0,53
Gain $G_{mid}$	1,5 – 5,5 dB	9,0 – 13,0 dB	-1,0 – 2,0 dB	7,0 dB
Gain $G_{125}$	3,0 – 6,0 dB	9,0 – 13,0 dB	-1,05 – 2,3 dB	13,7 dB
Initial Time Delay Gap ITDG	< 25 ms	< 20 ms	< 23 ms	24,5 ms
Clarity $C_{80}$	-3,0 – 0 dB	-2,0 – 2,0 dB	1,0 – 3,0 dB	-5,5 dB

# Venues - the Rector's Palace



# Venues - the Rector's Palace

Intervals of the recommended hall volume per seat, depending on the purpose of the hall (Long)

Auditorium type	Volume per seat (m <sup>3</sup> )			
	min.	mean	max.	Knežev dvor
Halls for speech	2,3	3,1	4,3	9,7
Concert halls	6,2	7,8	10,8	9,7
Opera houses	4,5	5,7	7,4	9,7
Churches, sacral spaces	5,1	7,2	9,1	9,7
Multifunctional auditorium	5,1	7,1	8,5	9,7
Cinemas	2,8	3,5	5,1	9,7

# Venues - the Rector's Palace

Estimation of speech intelligibility depending on the number value of the STI parameter.

Speech intelligibility evaluation	STI
very bad	$< 0,32$
bad	$0,32 - 0,45$
average	$0,45 - 0,60$
good	$0,60 - 0,75$
excellent	$> 0,75$

# Venues - the Rector's Palace

The Rector's Palace	$RT_{60}$ (s)	$EDT$ (s)	$BQI$	$G_{mid}$ (dB)	$C_{80}$ (dB)	$ITDG$ (ms)	$V/N$ (m <sup>3</sup> /pers.)	$STI$
Measured values	3.80	3.72	0.74	7.0	-5.5	24.50	9.7	0.36
Symphonical music								
Chamber music								
Opera								
Speech								
Cinema								

# Venues - Revelin Fortress

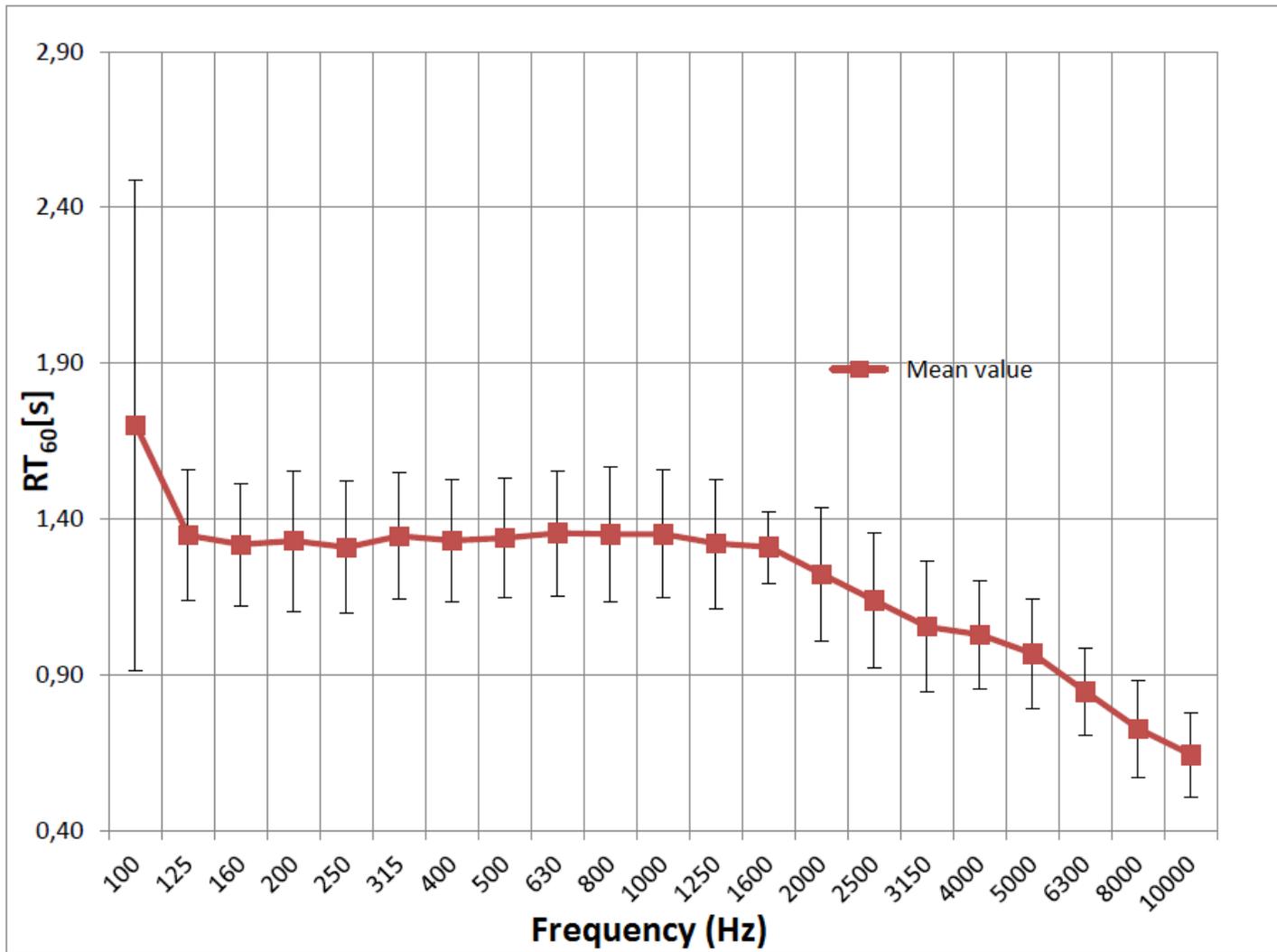
- 15<sup>th</sup> century
- fortification, treasury, municipal headquarters
- terrace - summer theatre
- interior - modern concerts
- volume = 1500 m<sup>3</sup>
- 220 seats



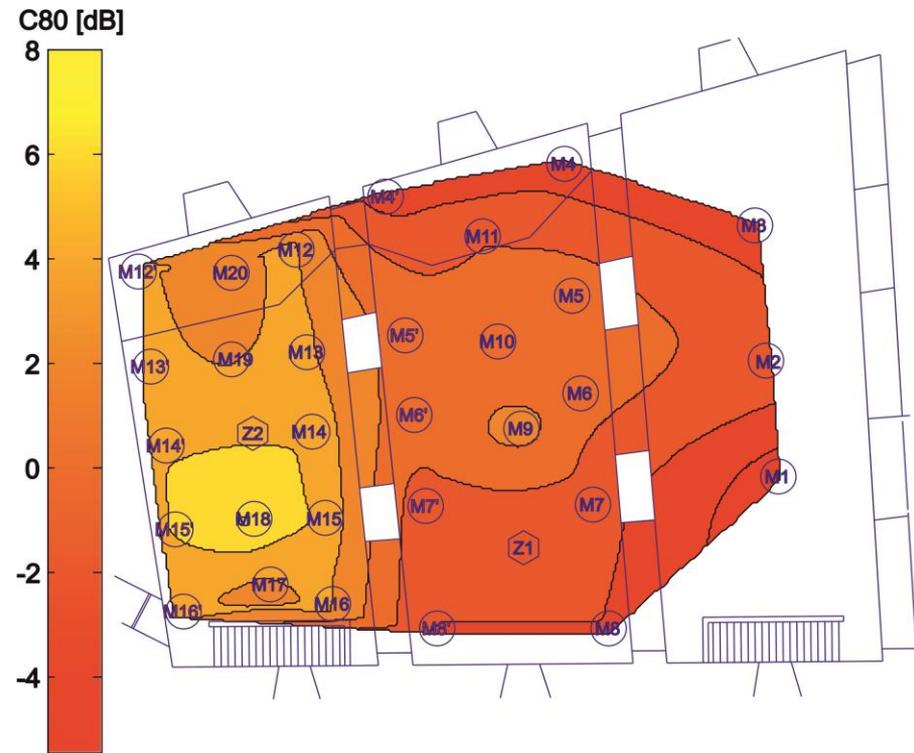
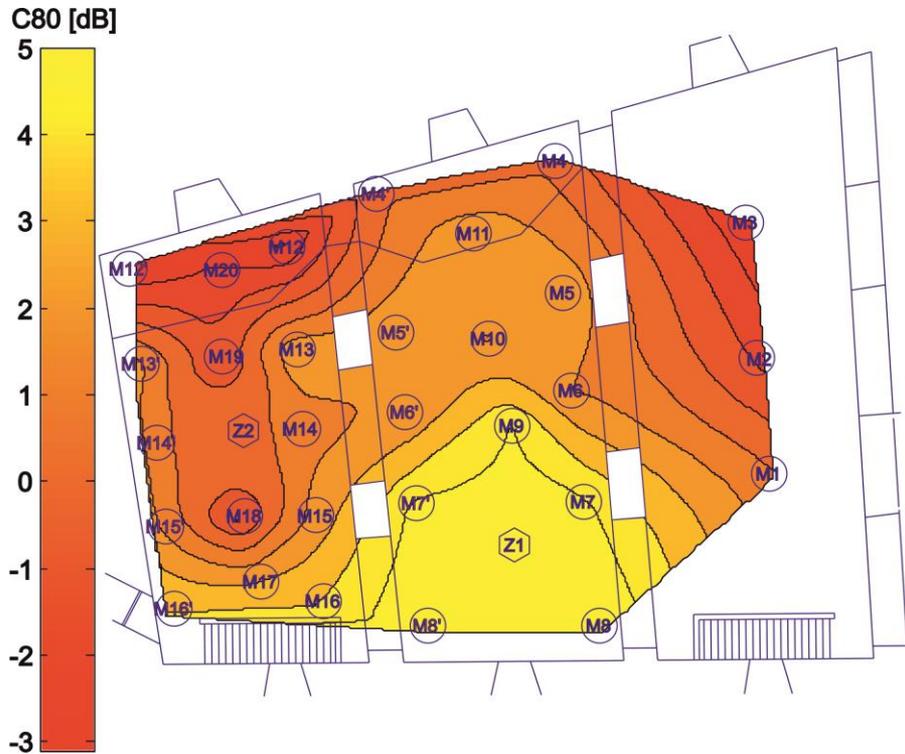
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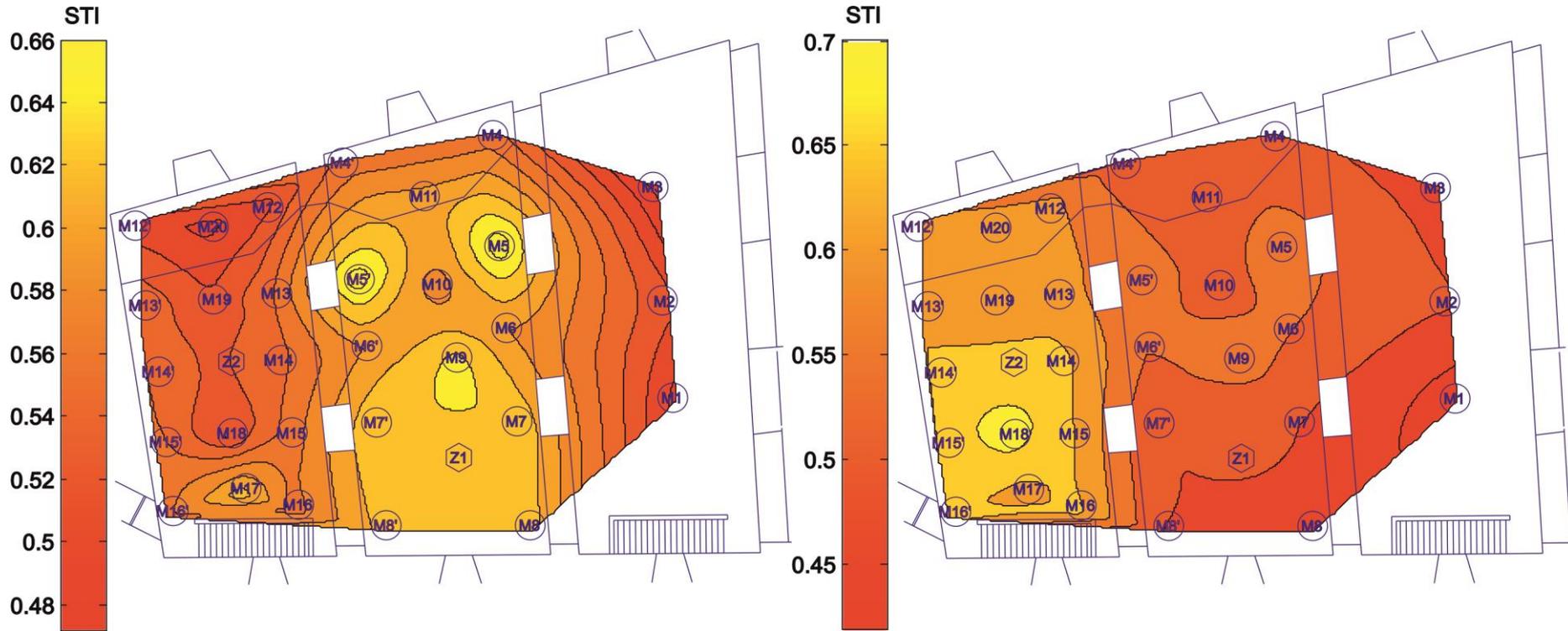
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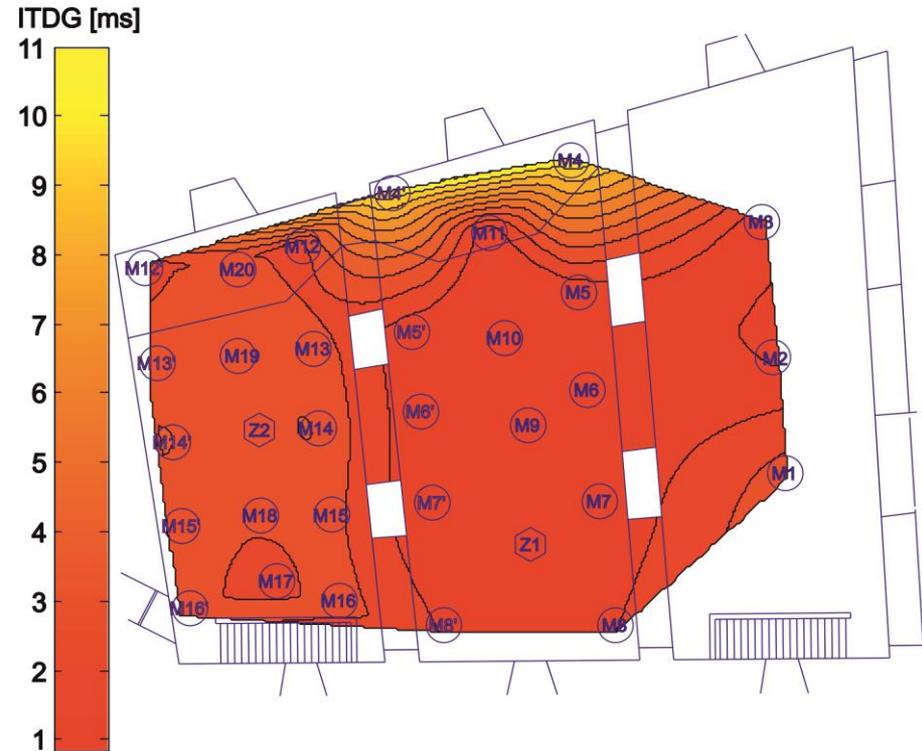
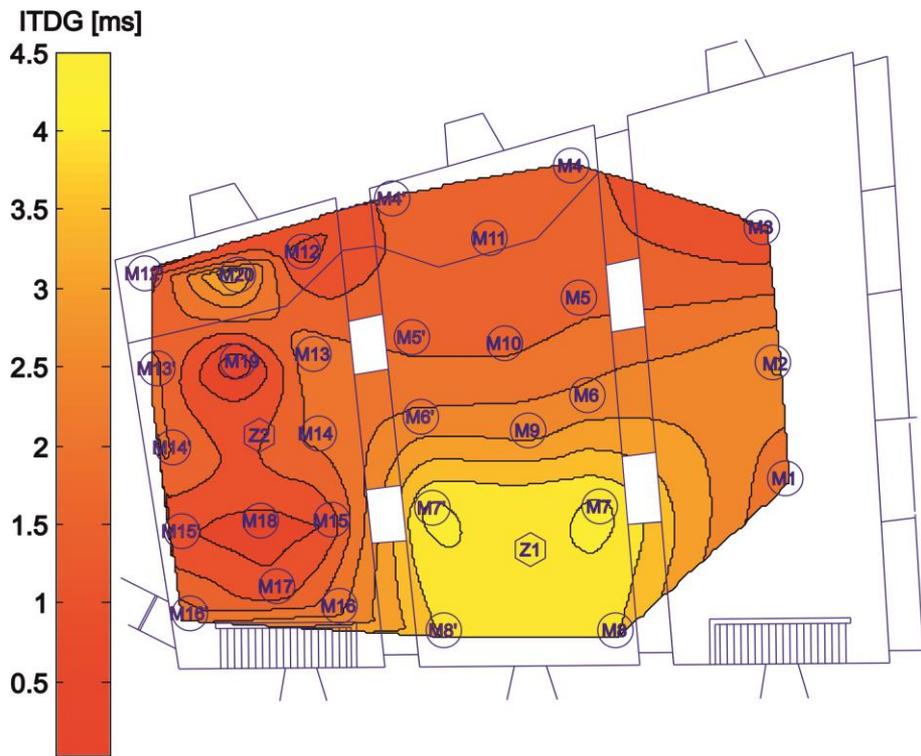
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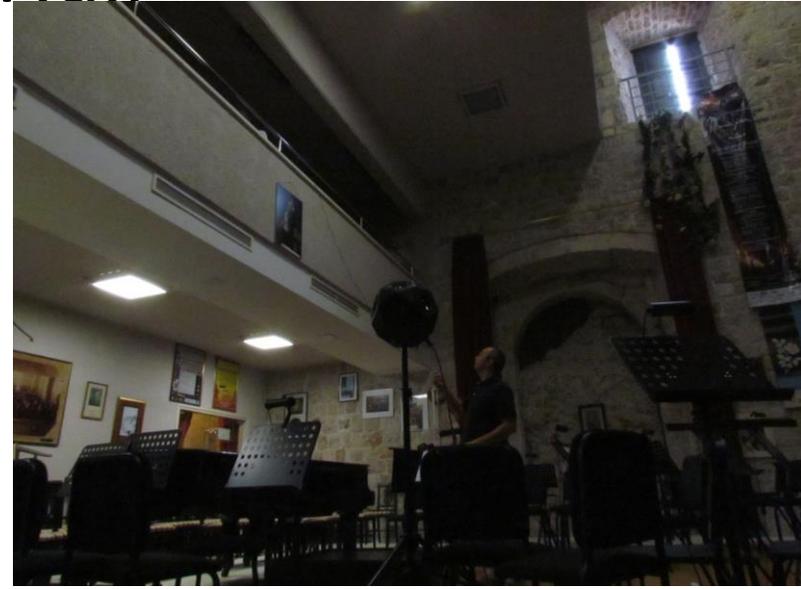
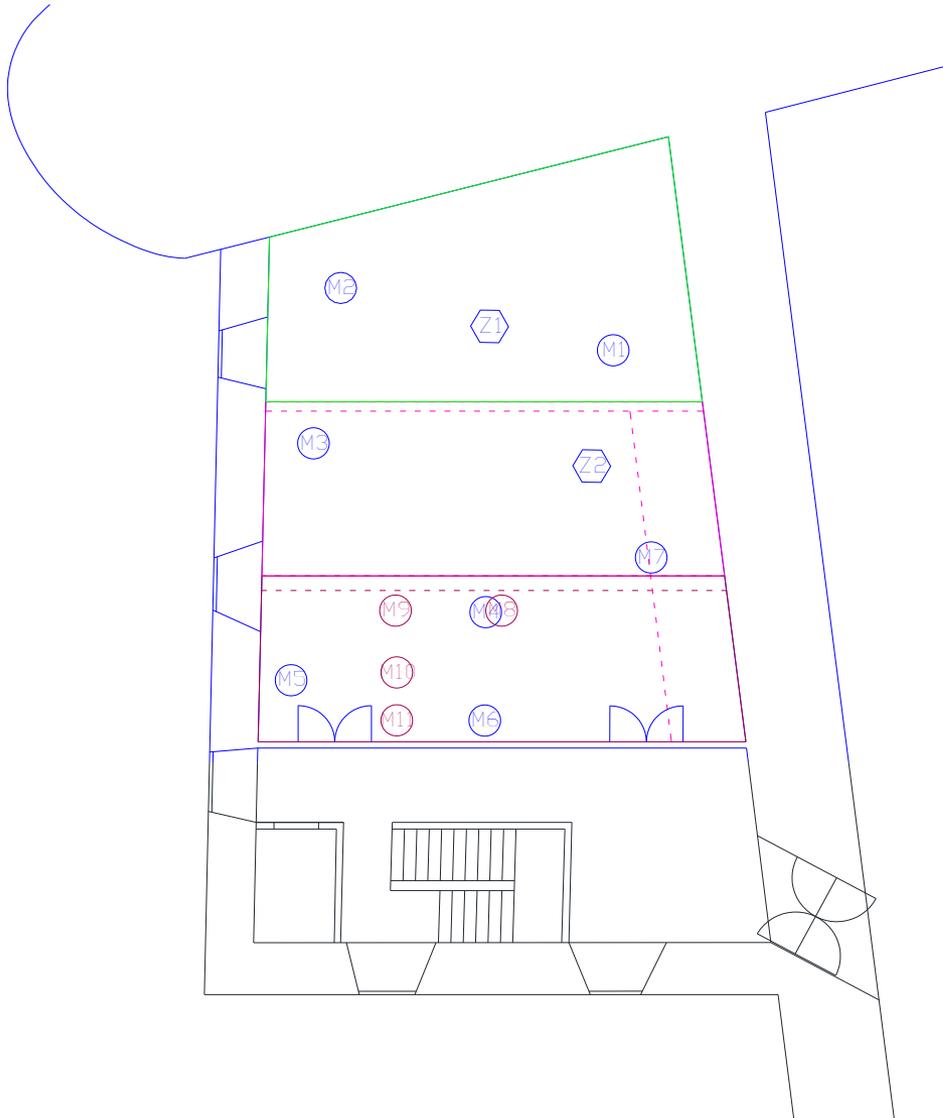
Revelin Fortress	$RT_{60}$ (s)	$EDT$ (s)	$BQI$	$G_{mid}$ (dB)	$C_{80}$ (dB)	$ITDG$ (ms)	$V/N$ ( $m^3$ /pers.)	$STI$
Measured values	1.34	1.30	0.63	0.7	1.6	2.56	6.8	0.58
Symphonical music								
Chamber music								
Opera								
Speech								
Cinema								

# Venues - Slanica Concert Hall

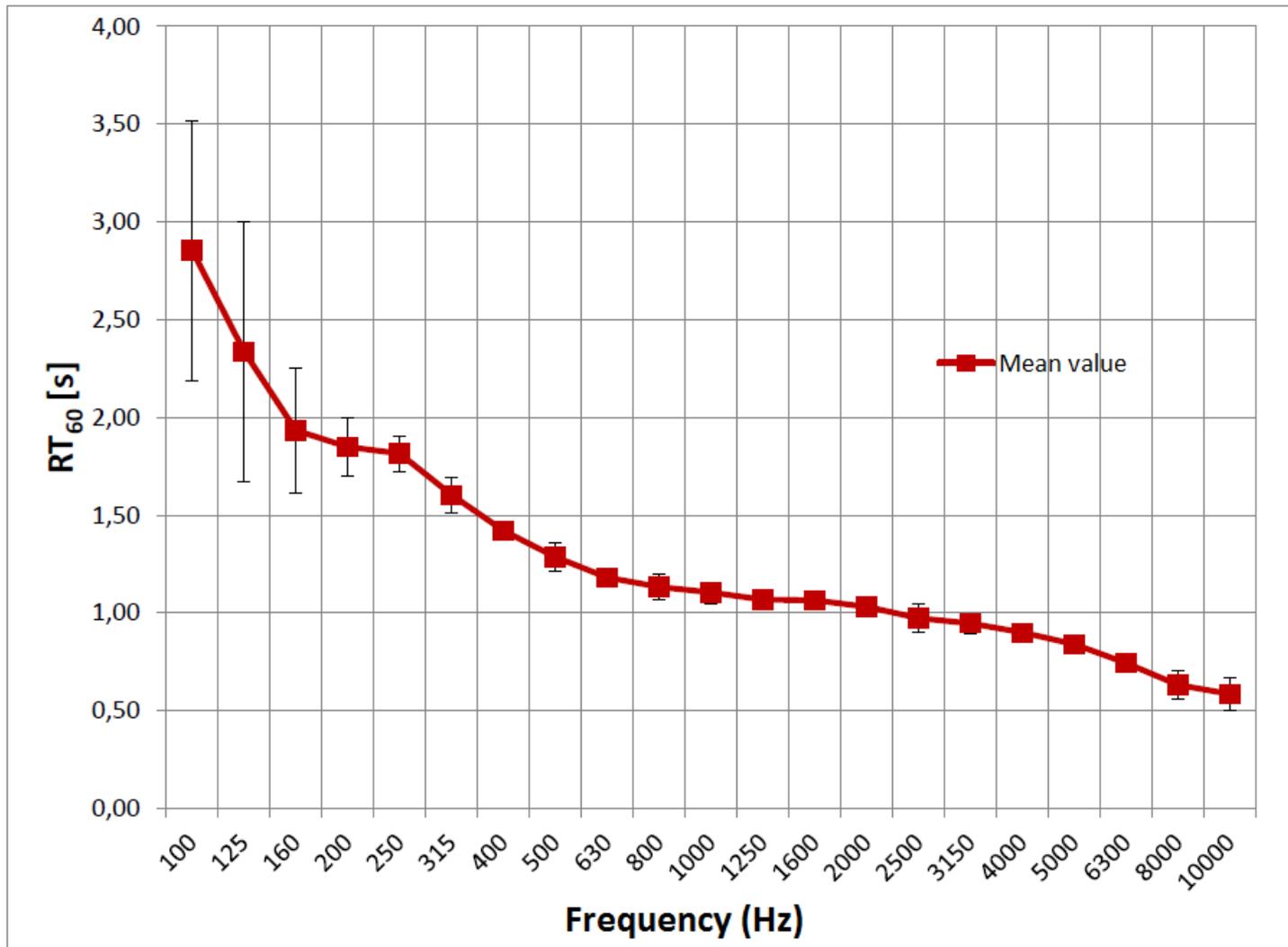
- a part of Revelin Fortress
- rehearsal space for Dubrovnik Symphony Orchestra
- volume = 685m<sup>3</sup>
- 170 seats



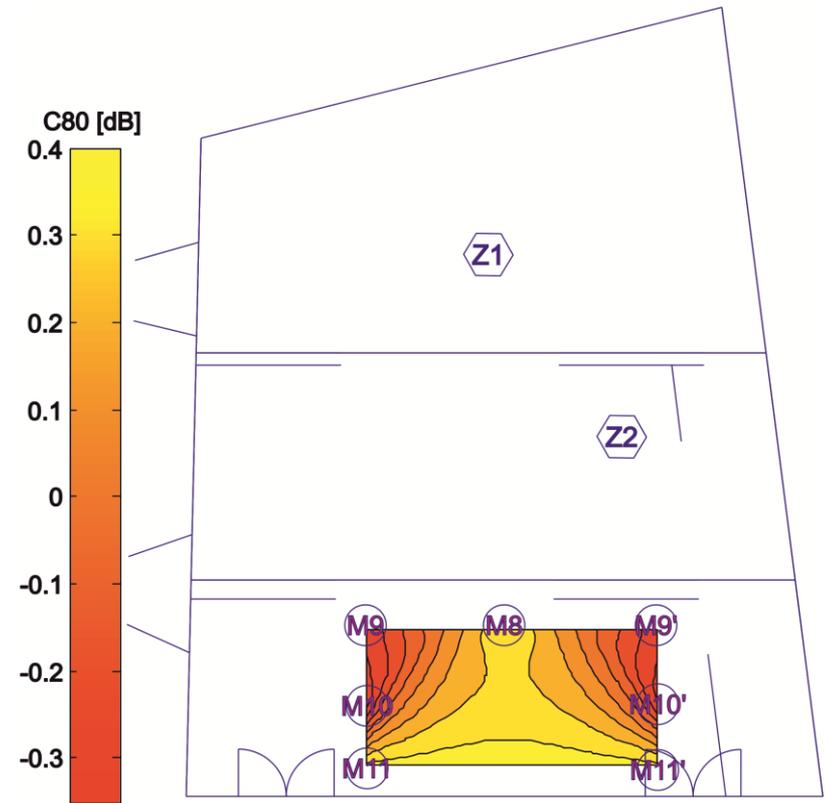
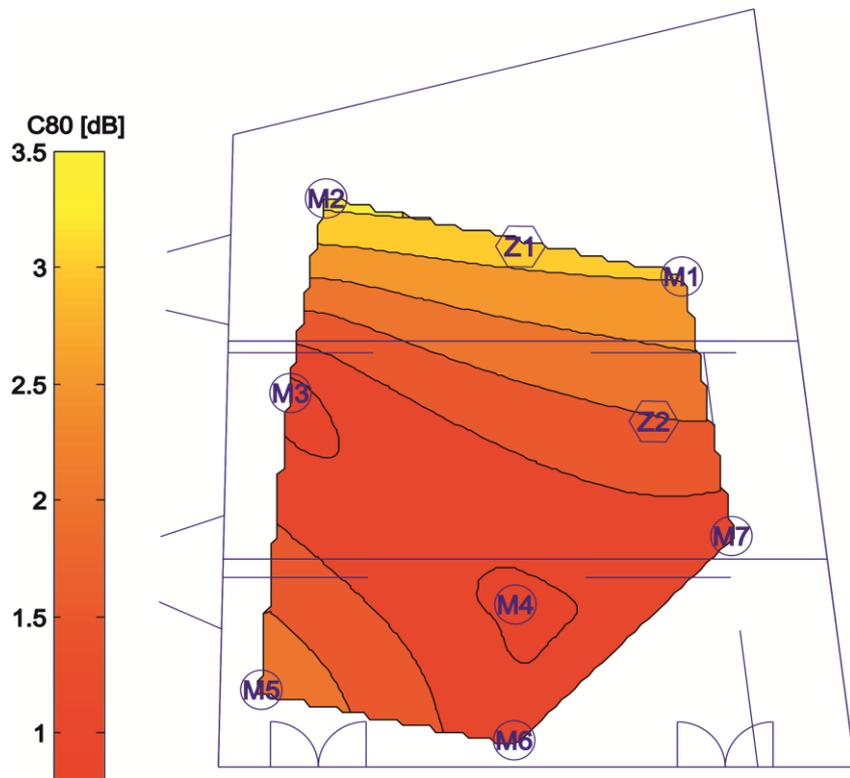
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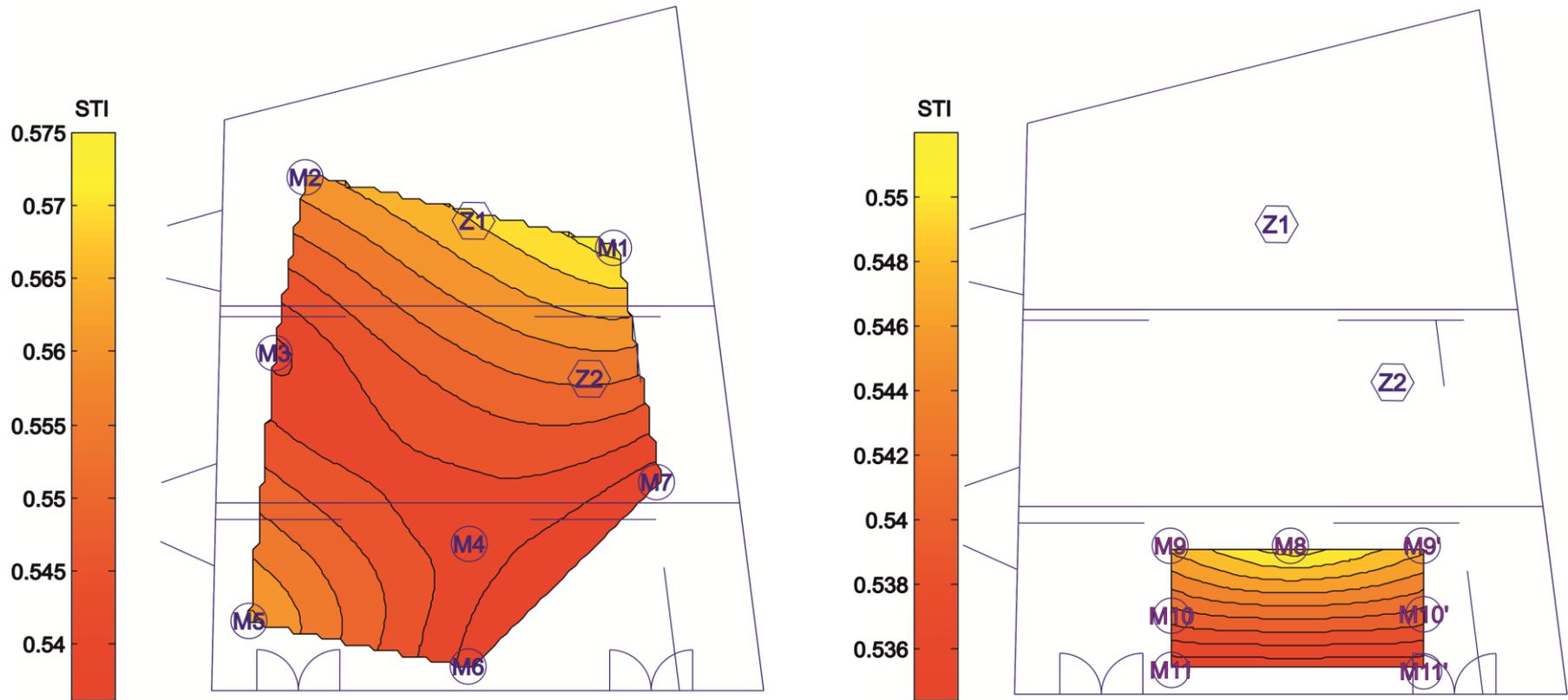
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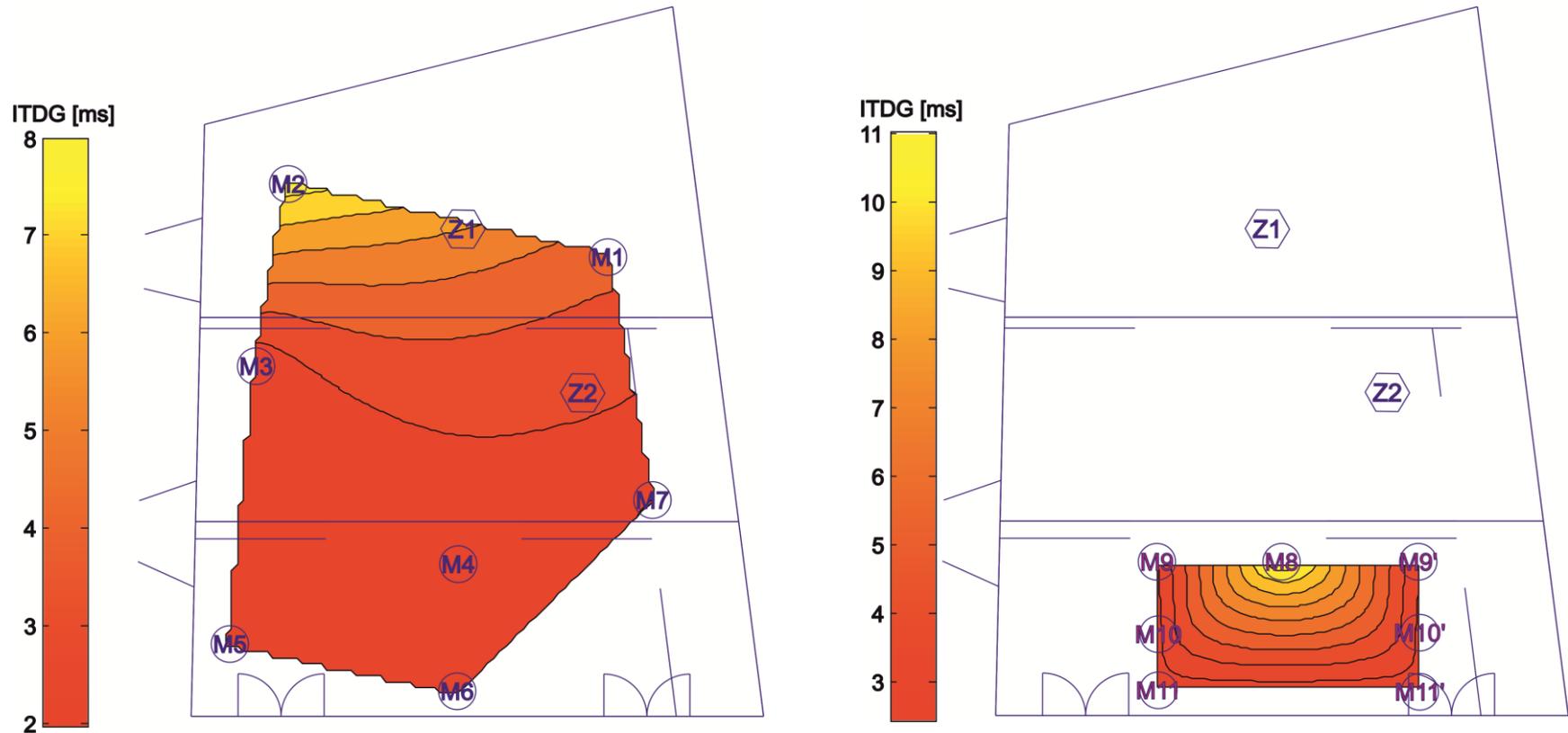
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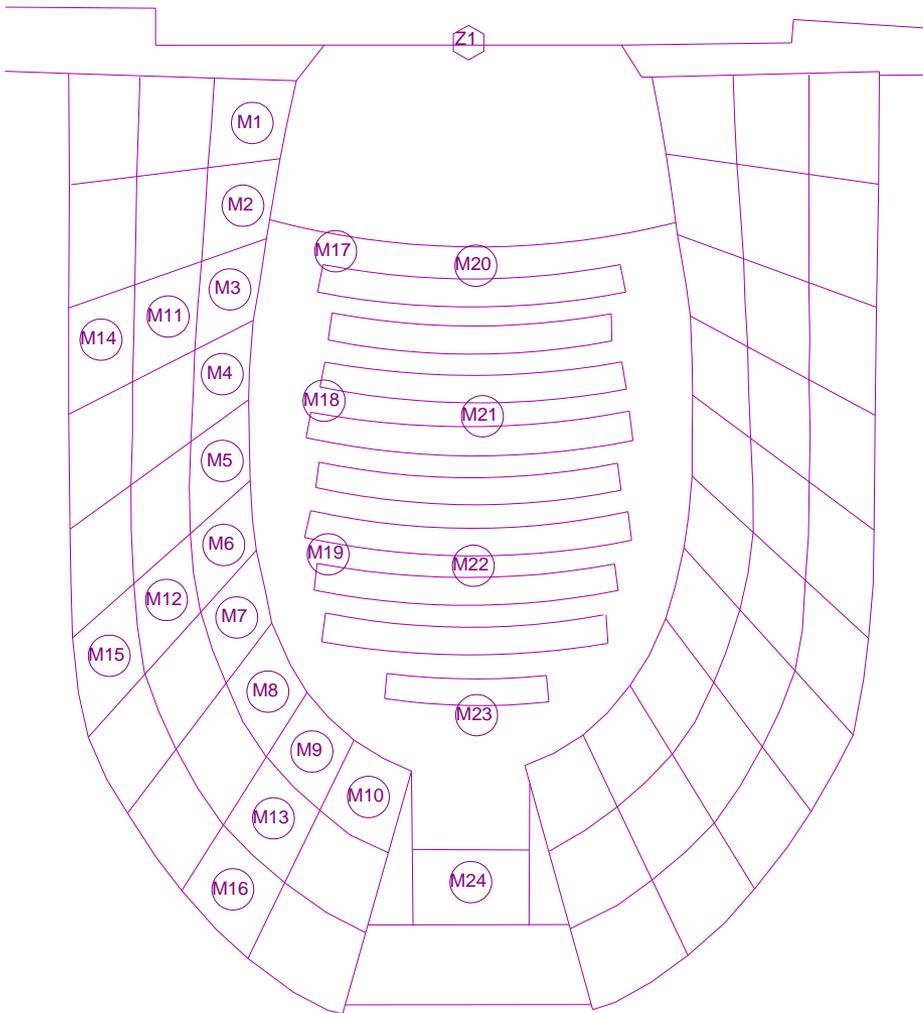
Slanica Concert Hall	$RT_{60}$ (s)	$EDT$ (s)	$BQI$	$G_{mid}$ (dB)	$C_{80}$ (dB)	$ITDG$ (ms)	$V/N$ (m <sup>3</sup> /pers.)	$STI$
Measured values	1.20	1.20	0.72	5.7	1.6	3.74	4.0	0.56
Symphonical music	Red	Red	Green	Green	Yellow	Green	Red	
Chamber music	Red	Red	Green	Red	Green	Green	Red	
Opera	Red	Red	Yellow	Red	Green	Green	Green	
Speech	Red	Red					Green	Yellow
Cinema	Red	Red					Green	Green

# Venues - Marin Držić Theatre

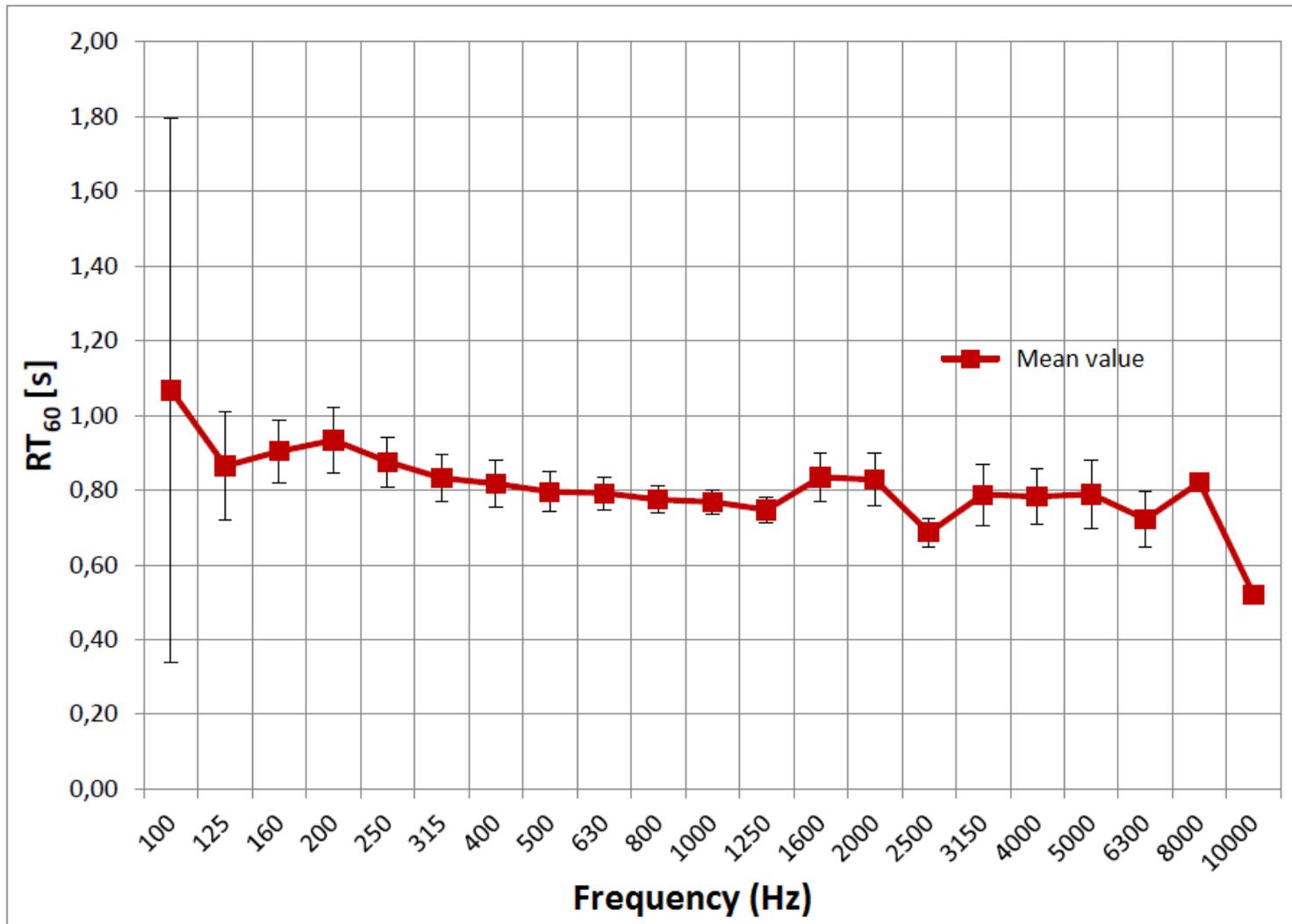
- 19<sup>th</sup> century
- long tradition of theatre performance
- volume = 1640 m<sup>3</sup>
- 283 seats



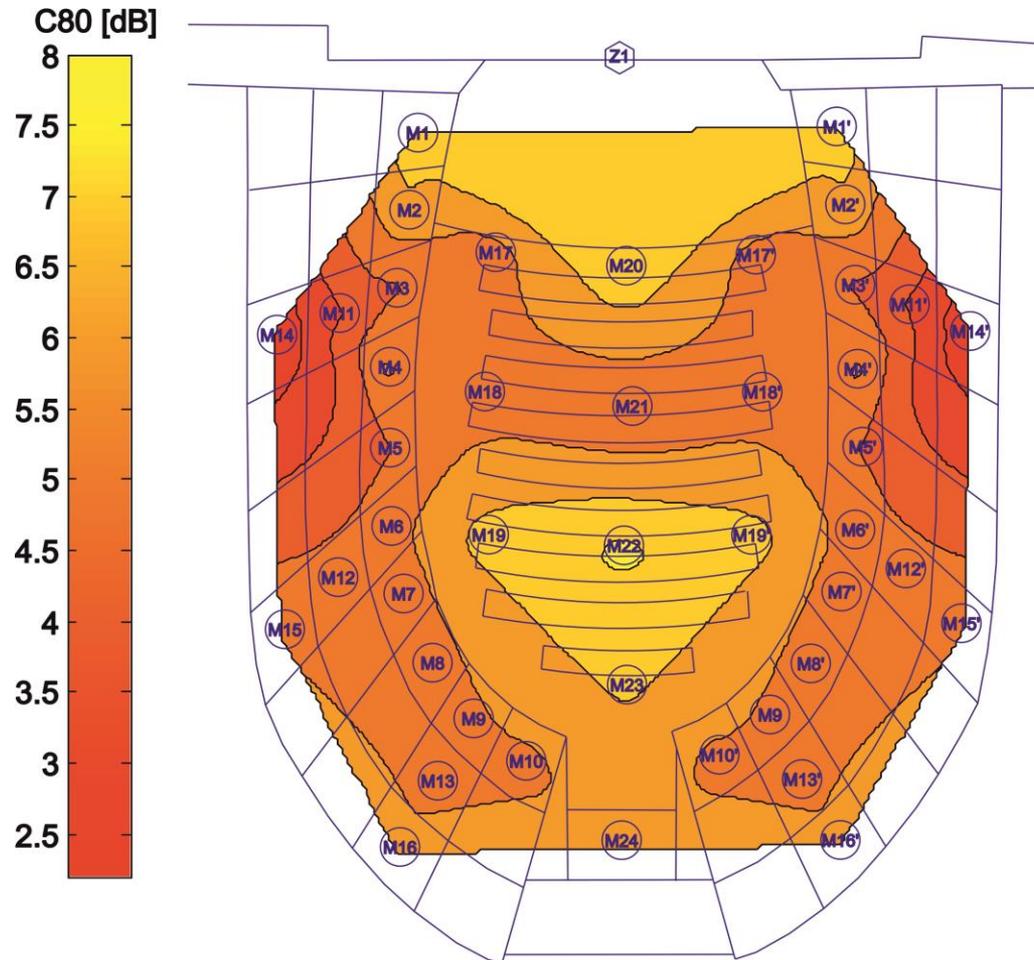
# Venues - Marin Držić Theatre



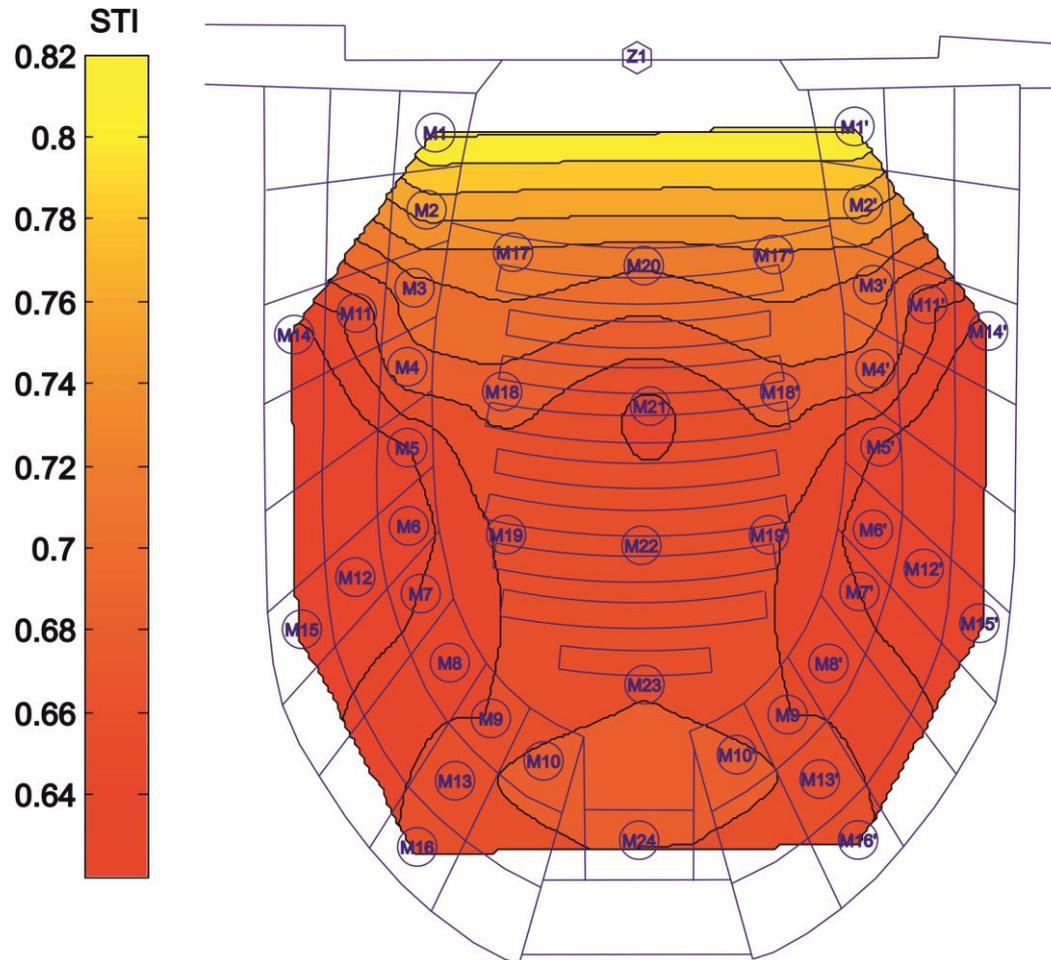
# Venues - Marin Držić Theatre



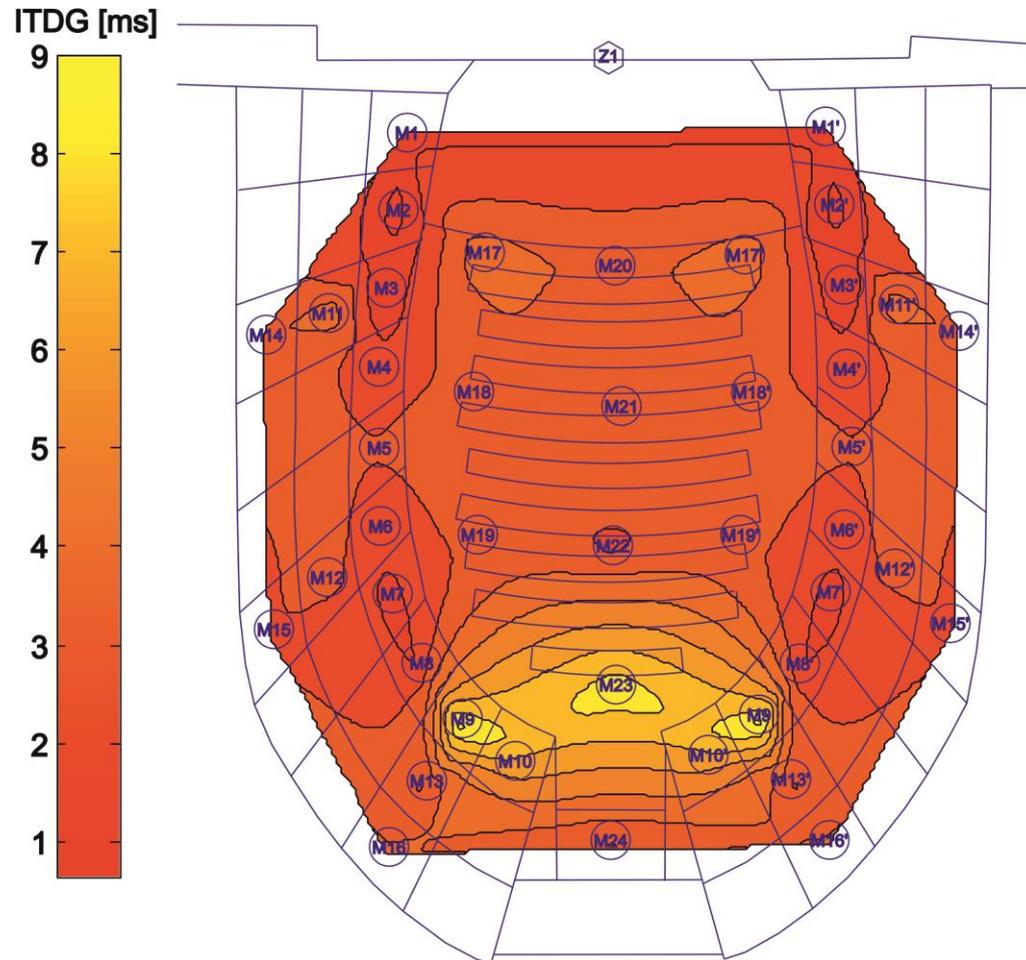
# Venues - Marin Držić Theatre



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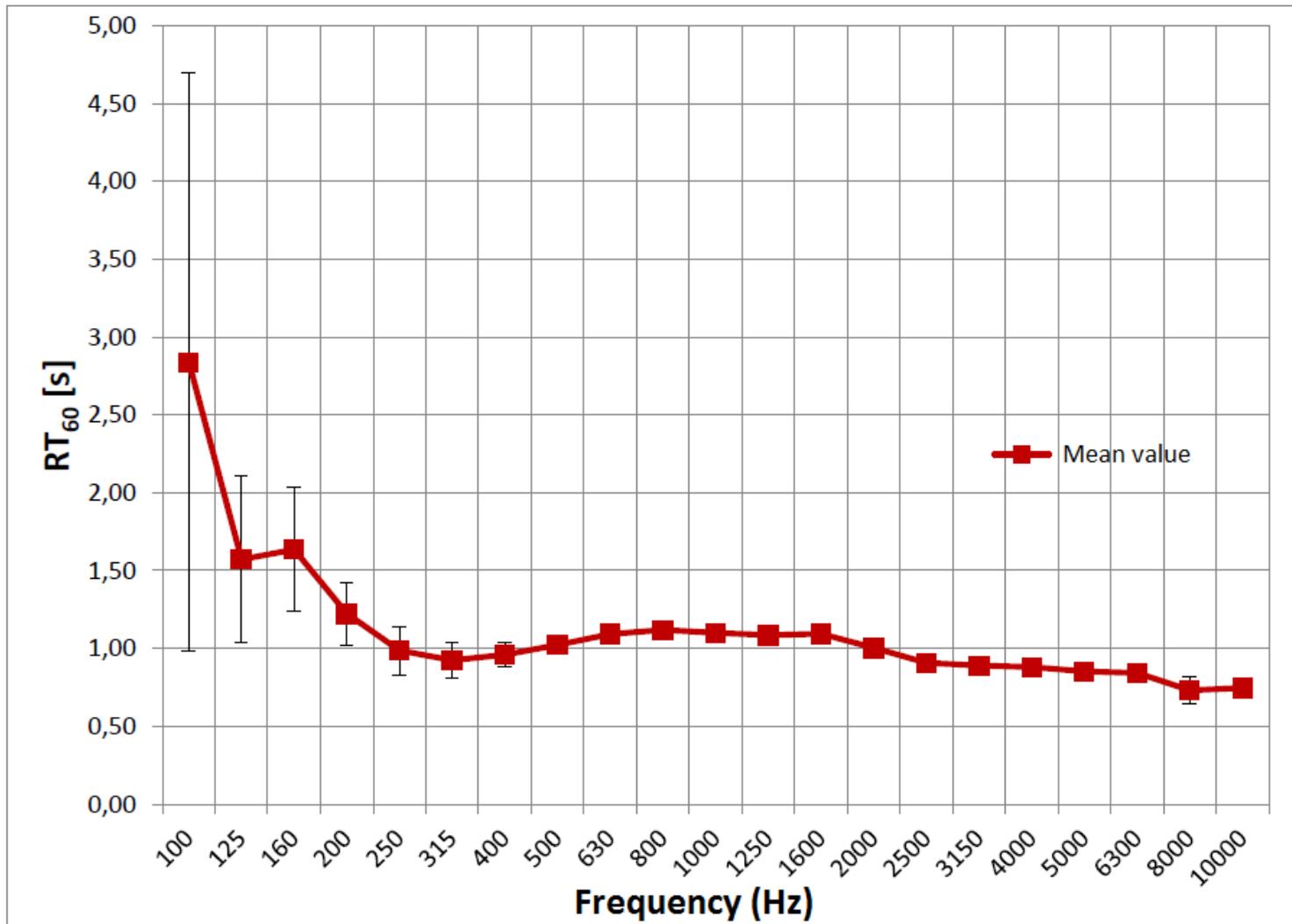
Marin Držić Theatre	$RT_{60}$ (s)	$EDT$ (s)	$BQI$	$G_{mid}$ (dB)	$C_{80}$ (dB)	$ITDG$ (ms)	$V/N$ (m <sup>3</sup> /pers.)	$STI$
Measured values	0.78	0.72	0.71	1.6	5.9	4.20	5.8	0.68
Symphonical music	Red	Red	Green	Green	Red	Green	Red	
Chamber music	Red	Red	Green	Red	Red	Green	Yellow	
Opera	Red	Red	Yellow	Green	Red	Green	Green	
Speech	Green	Yellow					Red	Green
Cinema	Red	Red					Red	Green

# Venues - Sloboda Movie Theatre

- modern
- movie screenings
- volume = 1350 m<sup>3</sup>
- 160 seats



# Venues - Sloboda Movie Theatre



# Sloboda Movie Theatre

Sloboda Movie Theatre	$RT_{60}$ (s)	$EDT$ (s)	$BQI$	$G_{mid}$ (dB)	$C_{80}$ (dB)	$ITDG$ (ms)	$V/N$ (m <sup>3</sup> /pers.)	$STI$
Measured values	1.06	0.94	0.75	4.6	3.6	4.38	7.7	0.62
Symphonical music								
Chamber music								
Opera								
Speech								
Cinema								

# Suitability for primary purpose

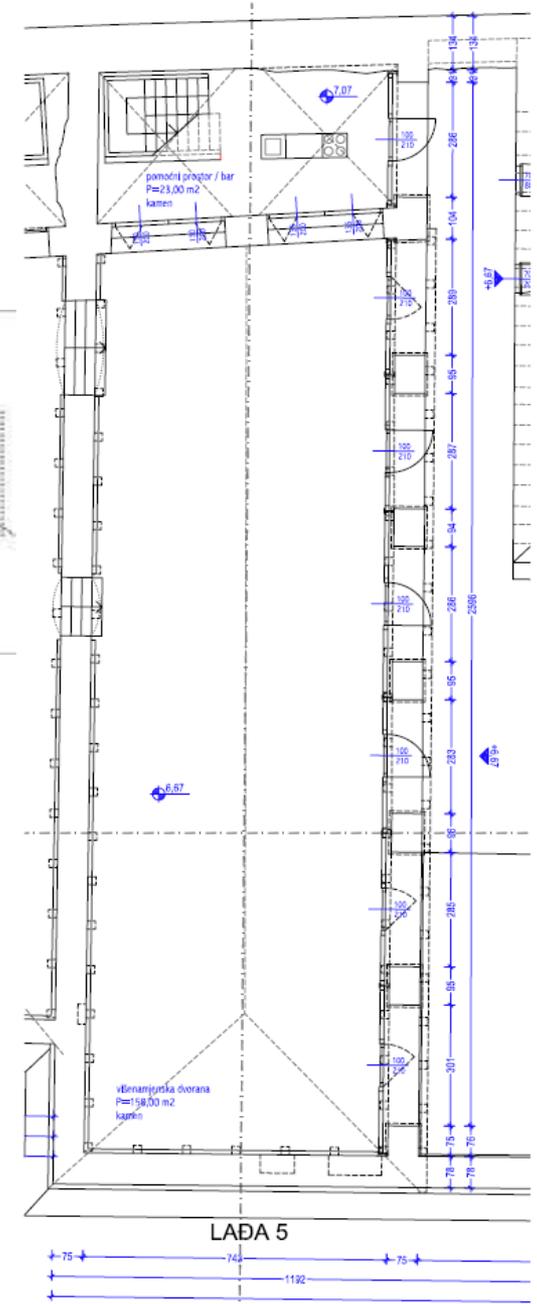
	Rector's Palace	Revelin Fortress	Slanica Concert Hall	Marin Držić Theatre	Sloboda Movie Theatre
$RT_{60}$ (s)	<b>3.80</b>	<b>1.34</b>	<b>1.20</b>	<b>0.78</b>	<b>1.06</b>
$EDT$ (s)	<b>3.72</b>	<b>1.30</b>	<b>1.20</b>	<b>0.72</b>	<b>0.94</b>
$C_{50}$ (dB)	<b>-8.1</b>	<b>-1.3</b>	<b>-1.3</b>	<b>2.1</b>	<b>0.1</b>
$C_{80}$ (dB)	<b>-5.5</b>	<b>1.6</b>	<b>1.6</b>	<b>5.9</b>	<b>3.6</b>
$G_{mid}$ (dB)	<b>7.0</b>	<b>0.7</b>	<b>5.7</b>	<b>1.6</b>	<b>4.6</b>
$LF_E$	<b>0.20</b>	<b>0.10</b>	<b>0.23</b>	<b>0.12</b>	<b>0.13</b>
$BQI$	<b>0.74</b>	<b>0.63</b>	<b>0.72</b>	<b>0.71</b>	<b>0.75</b>
$STI$	<b>0.36</b>	<b>0.58</b>	<b>0.56</b>	<b>0.68</b>	<b>0.65</b>
$ITDG$ (ms)	<b>24.50</b>	<b>2.56</b>	<b>3.74</b>	<b>4.20</b>	<b>4.38</b>
$V$ (m <sup>3</sup> )	<b>2900</b>	<b>1500</b>	<b>685</b>	<b>1640</b>	<b>1350</b>
$N$	<b>300</b>	<b>220</b>	<b>170</b>	<b>283</b>	<b>175</b>
$V/N$ (m <sup>3</sup> /prs.)	<b>9.7</b>	<b>6.8</b>	<b>4.0</b>	<b>5.8</b>	<b>7.7</b>

# Venues - Lazareti

- built in 1642
- old Dubrovnik harbour quarantine
- volume = 1000 m<sup>3</sup>
- 166 seats



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# Conclusions

- spaces not built for their present purpose → partly acoustically inappropriate
- certain improvement possible in some spaces (historical appeal)
- evaluation in the unoccupied state → improvement with people present
- evaluation of suitability using a novel table with colour-coded suitability marks (red for unsuitable, yellow for borderline suitable and green for suitable)

**Thank you for your attention!**