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Akustička ugoda u zatvorenim prostorima

Prof. dr. sc. Kristian Jambrošić

Fakultet elektrotehnike i računarstva, Zagreb



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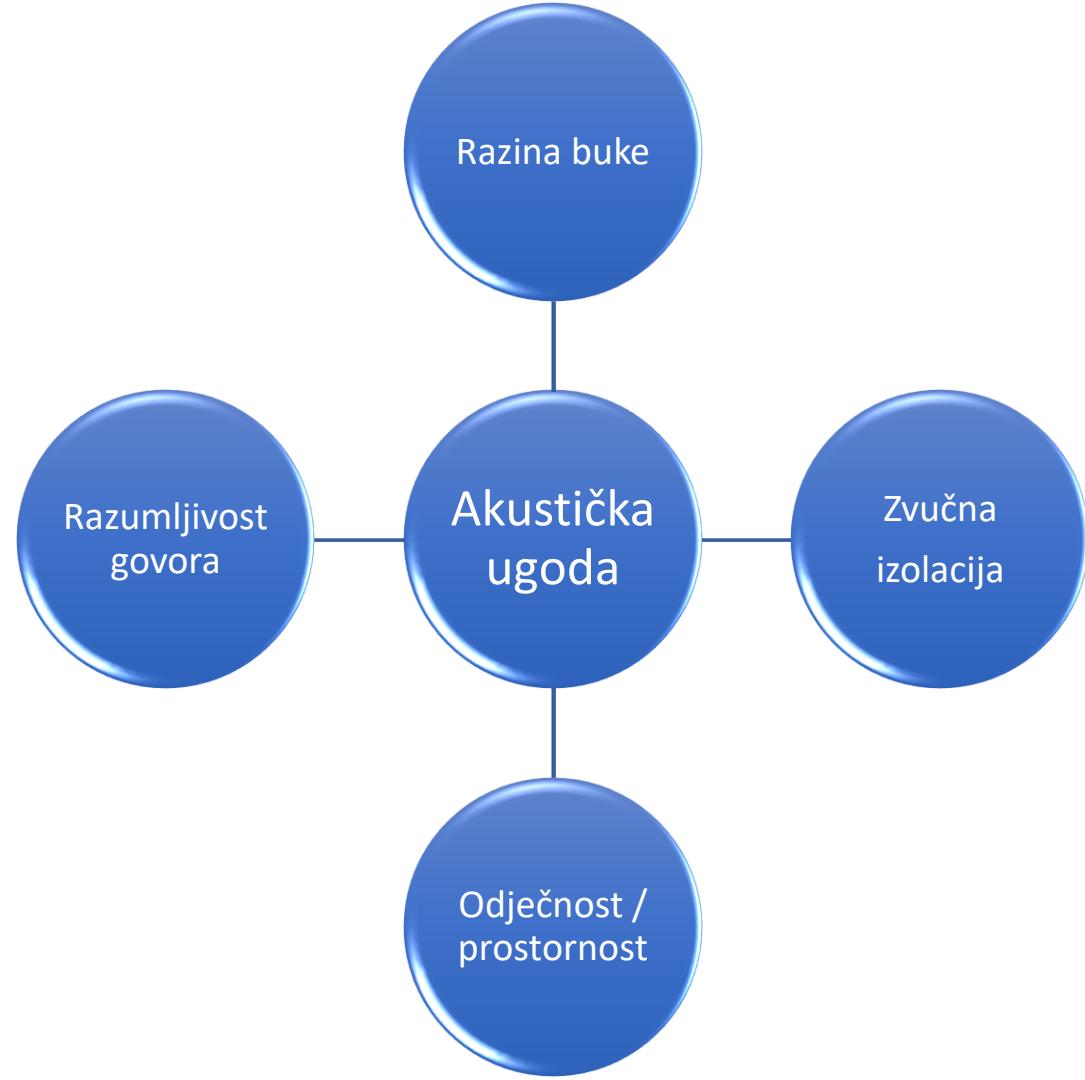


Sadržaj predavanja

- akustička ugoda (akustički komfor)
 - buka i dopuštene razine
 - akustički parametri prostora
 - optimalne vrijednosti parametara
- primjeri dobre i loše prakse akustičke obrade prostora
- vizualizacija i auralizacija kao alati u dizajnu prostora



Što određuje akustičku ugodu?

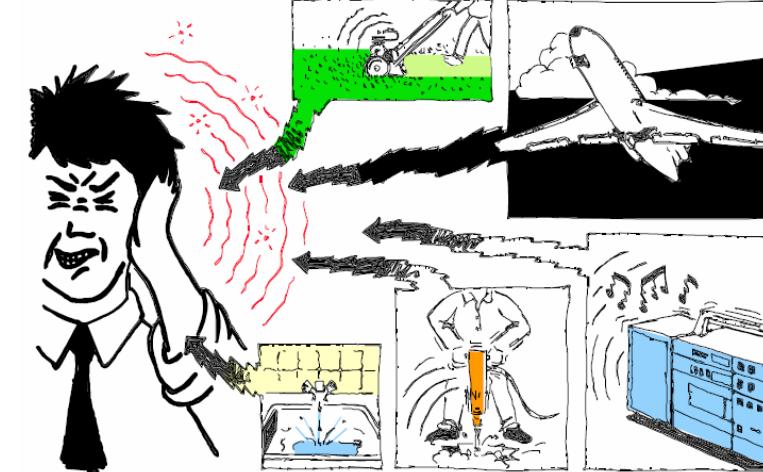
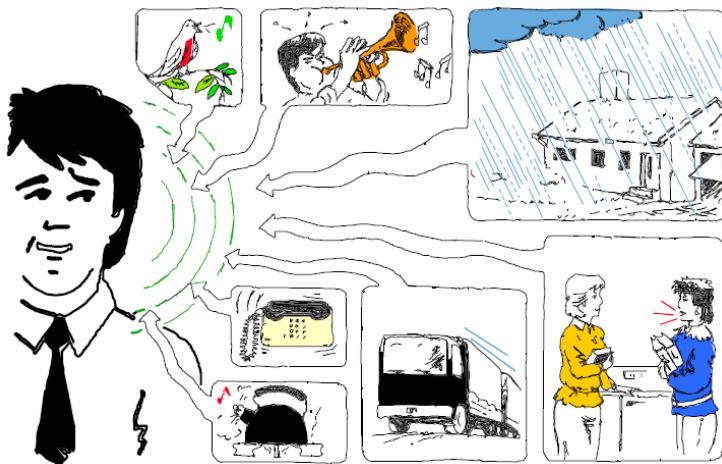




Što je buka?

Buka je:

- smetajući zvuk **Razine veće od granično propisane ili preporučene?**
- “Čujni otpad naše civilizacije” (H. von Karajan)





Dopuštene razine

Pravilnik o zaštiti radnika od izloženosti buci na radu (NN 46/08)

R. br.	Opis posla	Najviša dopuštena razina buke $L_{A, eq}$ u dB(A)	
		(a) [*]	(b) [*]
1	Najzahtjeviji umni rad, vrlo velika usredotočenost, rad vezan za veliku odgovornost, najsloženiji poslovi upravljanja i rukovođenja	45	40
2	Pretežno umni rad koji zahtijeva usredotočenost, kreativno razmišljanje, dugoročne odluke istraživanje, projektiranje, komuniciranje sa skupinom ljudi	50	40
3	Zahtjevni uredski poslovi, liječničke ordinacije, dvorane za sastanke, školska nastava, neposredno govorno i/ili telefonsko komuniciranje	55	45
4	Manje zahtjevni uredski poslovi, pretežno rutinski umni rad koji zahtijeva usredotočenje ili neposredno govorno i/ili telefonsko komuniciranje, komunikacijske centrale	60	50
5	Manje zahtjevni i uglavnom mehanizirani uredski poslovi, prodaja, vrlo zahtjevno upravljanje sustavima, fizički rad koji zahtijeva veliku pozornost i usredotočenost, zahtjevni poslovi montaže	65	55
6	Pretežno mehanizirani uredski poslovi, zahtjevno upravljanje sustavima, upravljačke kabine, fizički rad koji zahtijeva stalnu usredotočenost, rad koji zahtijeva nadzor sluhom, rad koji se obavlja na temelju zvučnih signala	70	60
7	Manje zahtjevni fizički poslovi koji zahtijevaju usredotočenost i oprez, manje zahtjevno upravljanje sustavima	75	65
8	Pretežno rutinski fizički rad sa zahtjevom na točnost, praćenje okoline slušanjem	80	65





Dopuštene razine

DIN 18041 – za prostore namijenjene govoru

Schalltechnische Anforderungen an die Raumnutzung	Störgeräuschpegel L_{NA} dB	Eignung ^a für eine Entfernung: Sprecher – Hörer		Eignung ^a für Personen mit Hörverlusten	Eignung ^a für die Wahrnehmung schwieriger oder fremdsprachiger Texte
		mittlere ^{b c}	grössere ^b		
I (mindest)	≤ 40 (laut)	+	-	-	-
II (mittlere)	≤ 35 (mittel)	+	o	o	o
III (hohe)	≤ 30 (leise)	+	+	+	+

^a) "+" geeignet, "o" bedingt geeignet, "-" nicht geeignet

^b) Für eine mittlere Entfernung zwischen Sprecher und Hörer kann üblicherweise ein Abstand von 5 m bis 8 m, für grössere Entfernungen > 8 m, angenommen werden.

^c) Auch geeignet für geringere Entfernungen zwischen Sprecher und Hörer bis etwa 5 m.

Tabelle 1 Einstufung der zulässigen Störgeräuschpegel gemäss DIN 18041 (Tabelle 1)



Dopuštene razine

ANSI/ASA S12.60/2010/Part 1 – za škole

Learning space ^{a)}	Greatest one-hour average A- and C-weighted sound level of exterior-source background noise ^{b), c)} (dB)	Greatest one-hour average A- and C-weighted sound level of interior-source background noise ^{c), d)} (dB)	Maximum permitted reverberation times for sound pressure levels in octave bands with midband frequencies of 500, 1000, and 2000 Hz (s)
Core learning space with enclosed volume $\leq 283 \text{ m}^3$ ($\leq 10\,000 \text{ ft}^3$)	35 / 55	35 / 55	0.6 s ^{e)}
Core learning space with enclosed volume $> 283 \text{ m}^3$ and $\leq 566 \text{ m}^3$ ($> 10\,000 \text{ ft}^3$ and $\leq 20\,000 \text{ ft}^3$)	35 / 55	35 / 55	0.7 s
Core learning spaces with enclosed volumes $> 566 \text{ m}^3$ ($> 20\,000 \text{ ft}^3$) and all ancillary learning spaces	40 / 60 ^{d)}	40 / 60 ^{d)}	No requirement

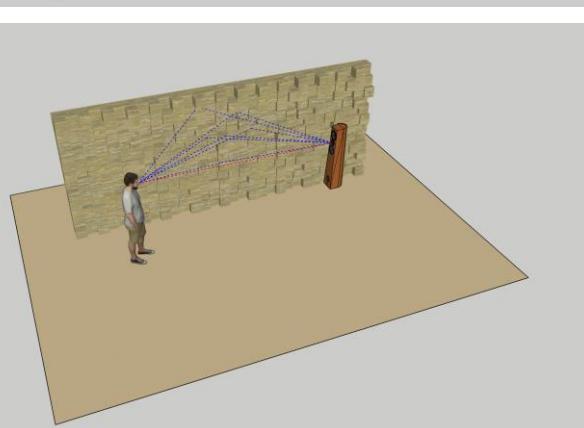
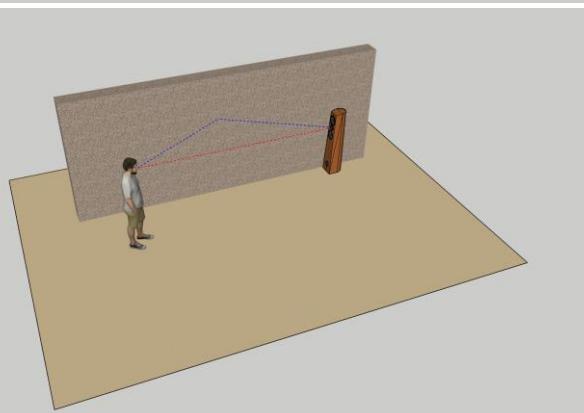
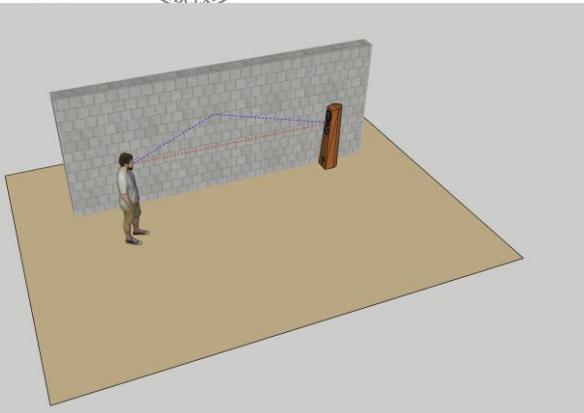
a) See 3.1.1.1 and 3.1.1.2 for definitions of core and ancillary learning spaces.
 b) The greatest one-hour average A- and C-weighted interior-source and the greatest one-hour average A- and C-weighted exterior-source background noise levels are evaluated independently and will normally occur at different locations in the room and at different times of day.
 c) See 5.2.2 for other limits on interior-source background noise level.
 d) See 5.2.3 for limits in corridors adjacent to classrooms.
 e) See 5.3.2 for requirement that core learning spaces $\leq 283 \text{ m}^3$ ($\leq 10\,000 \text{ ft}^3$) shall be readily adaptable to allow reduction in reverberation time to 0.3 s.
 f) The design location shall be at a height of 1 m above the floor and no closer than 1 m from a wall, window, or fixed object such as HVAC equipment or supply or return opening. See A.1.3 for measurement location.



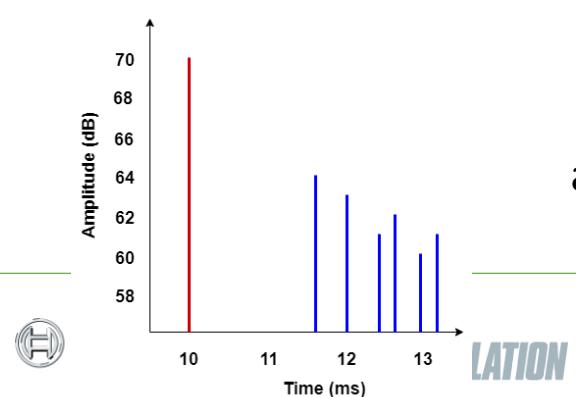
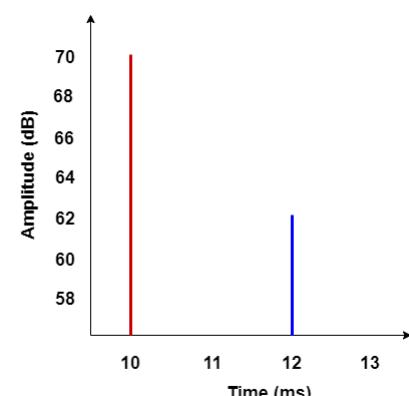
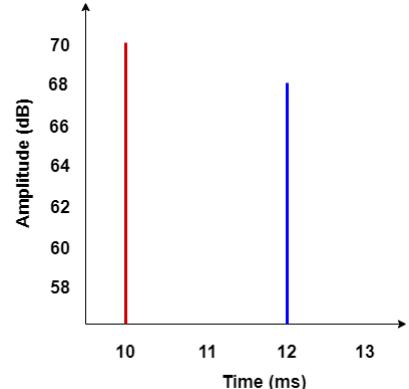
Dopuštene razine

WHO - Night noise guidelines for Europe

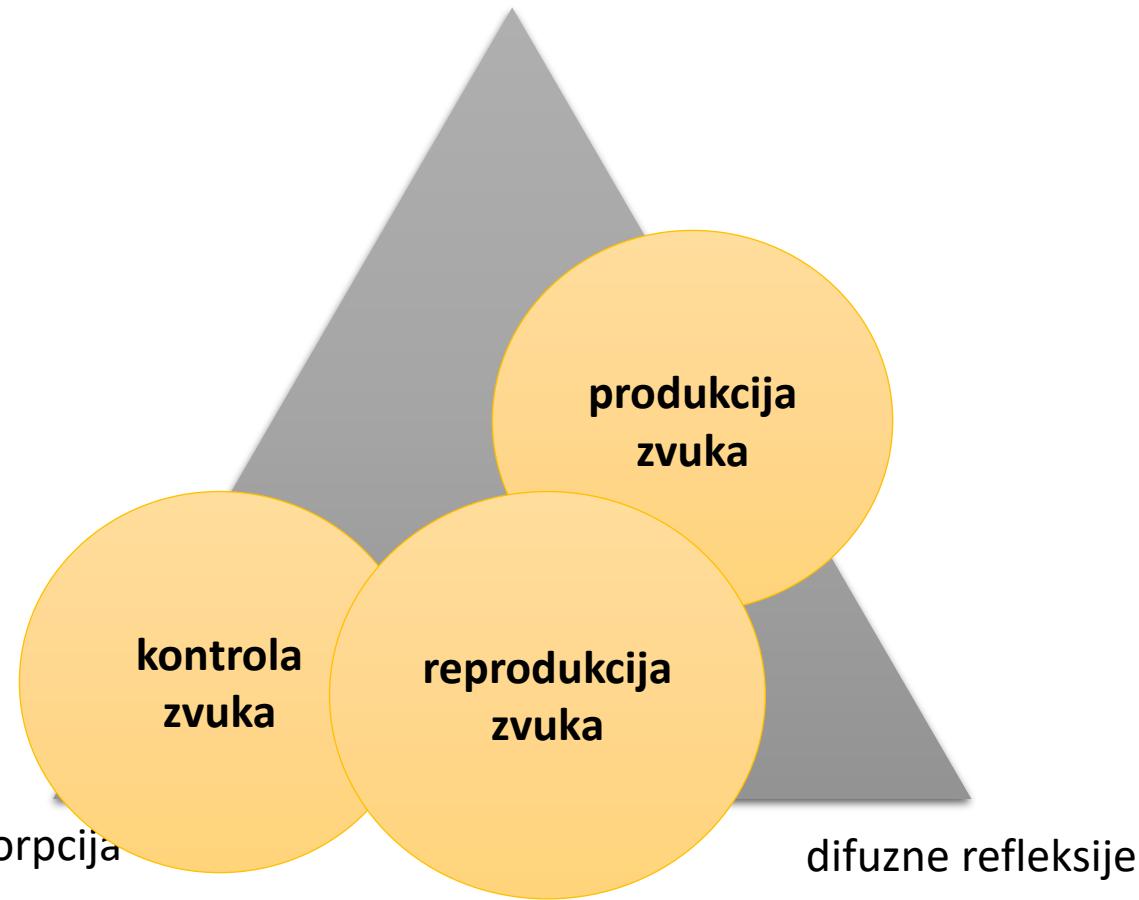
Average night noise level over a year $L_{night, outside}$	Health effects observed in the population
Up to 30 dB	Although individual sensitivities and circumstances may differ, it appears that up to this level no substantial biological effects are observed. $L_{night, outside}$ of 30 dB is equivalent to the no observed effect level (NOEL) for night noise.
30 to 40 dB	A number of effects on sleep are observed from this range: body movements, awakening, self-reported sleep disturbance, arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (for example children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. $L_{night, outside}$ of 40 dB is equivalent to the lowest observed adverse effect level (LOAEL) for night noise.
40 to 55 dB	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
Above 55 dB	The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.



Akustički dizajn prostora



zrcalne refleksije



LATION



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Jambrošić Theory vs. Practical Cases in
SUSTAINABLE Acoustics
Novi građevinski elementi d.o.o.





Akustički parametri

- Parametri za određivanje akust. osobine prostora (ISO 3382)

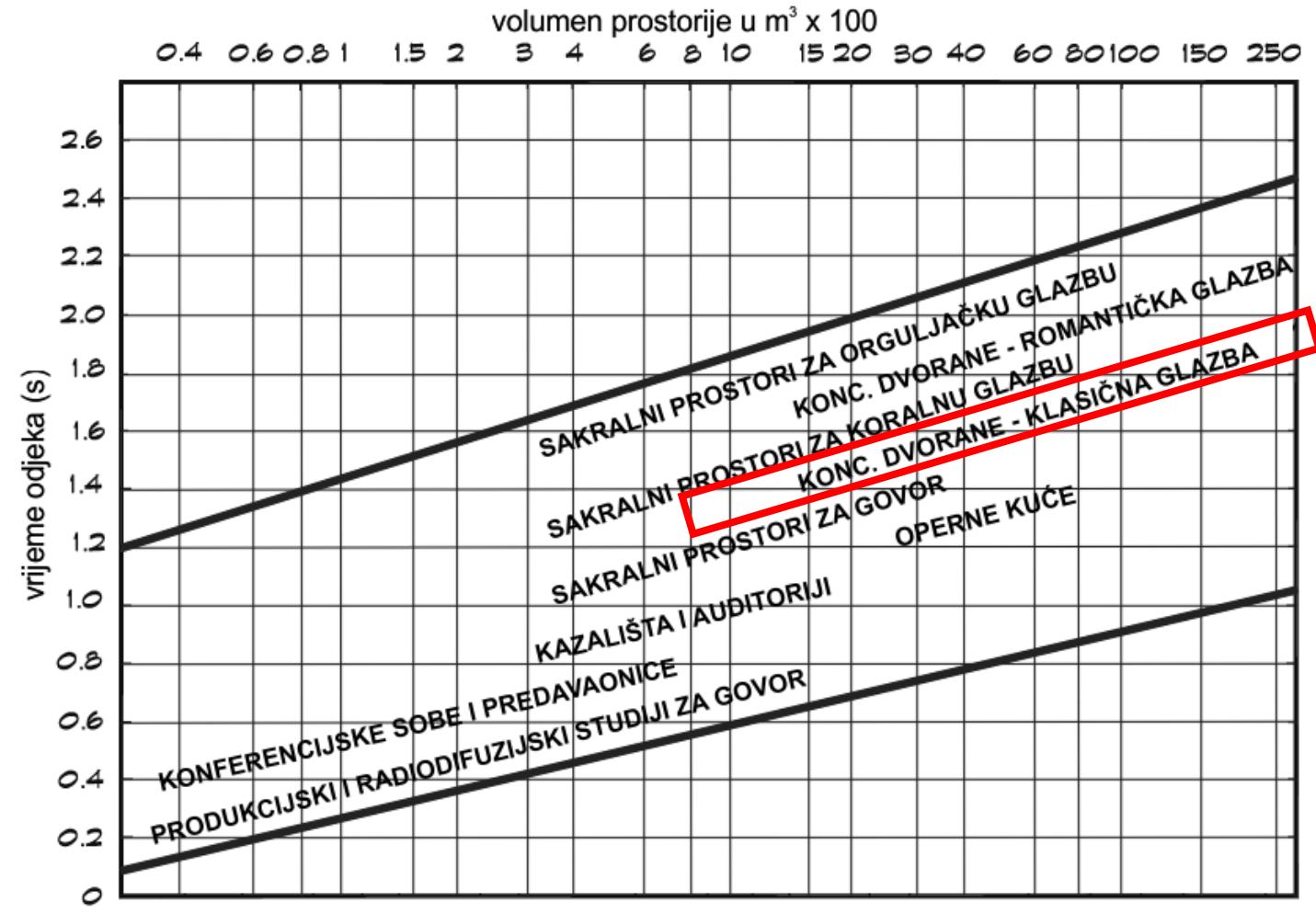
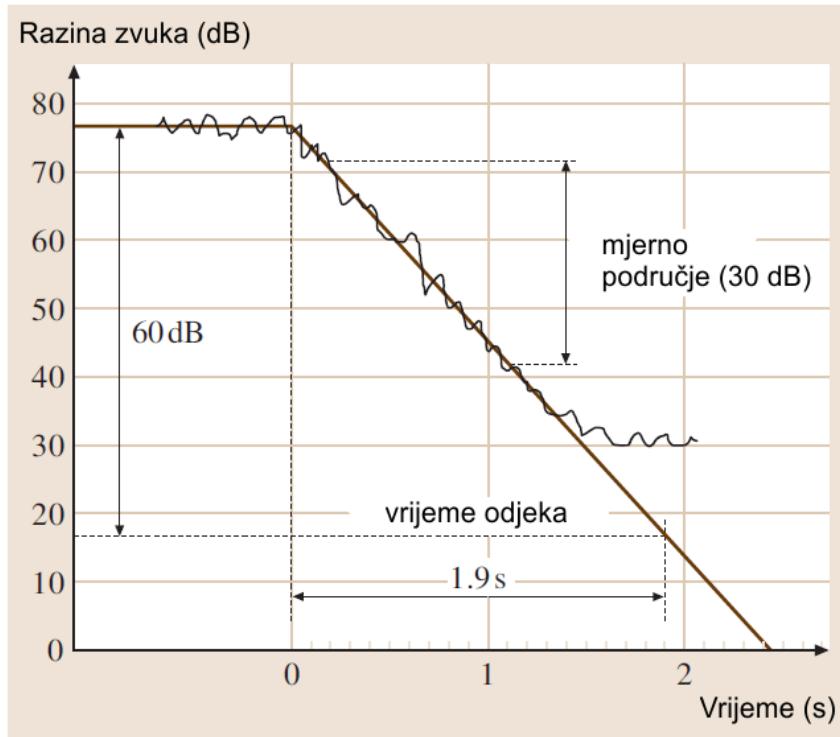
Parametar, oznaka (jedinica)	Subjektivni osjećaj
Vrijeme odjeka, T_{30} , T_{20} (s)	odječnost, glasnoća
Vrijeme ranog opadanja, EDT (s)	odječnost, izduženost
Centralno vrijeme, T_s (s)	jasnoća
Jasnoća, C_{80} , C_{50} (dB)	jasnoća
Definiranost, D_{50} (%)	definiranost govora
Pojačanje, G (dB)	relativna razina zvuka
Udio bočne energije, IE_{20C} (%)	osjećaj prostornosti
Interauralni kofazni linearni korelacije IACC	osjećaj prostornosti

Neki se često upotrebljavaju i parametri razumljivosti govora:
STI, RASTI, Alcons



Akustički parametri

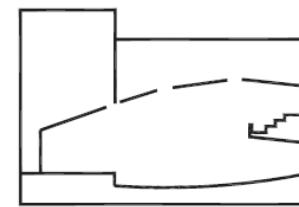
- Vrijeme odjeka, T_{60} (s)



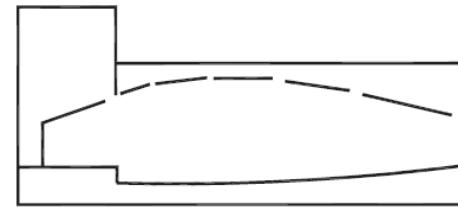
© Marshall Long: „Architectural Acoustics”, Associate Press 2005.



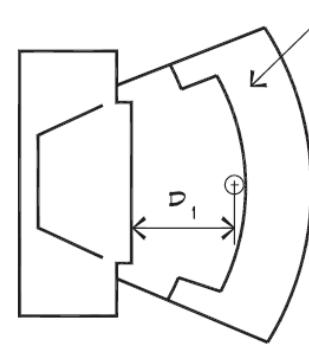
Primjeri dobre prakse



Section

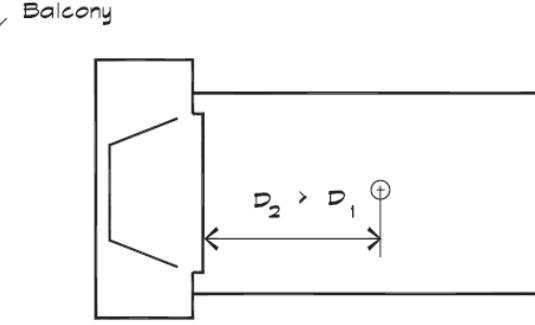


Section



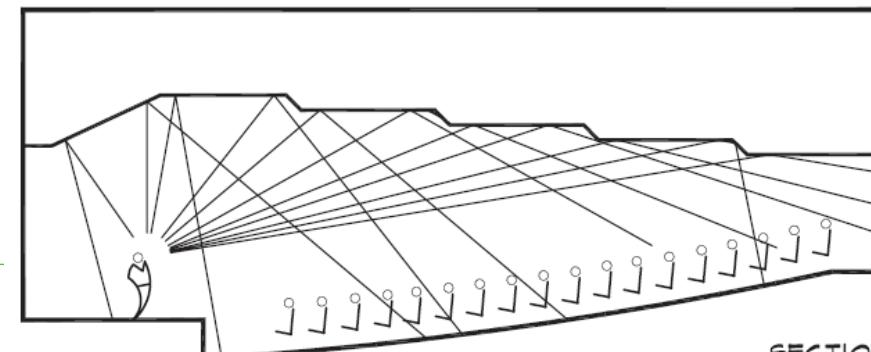
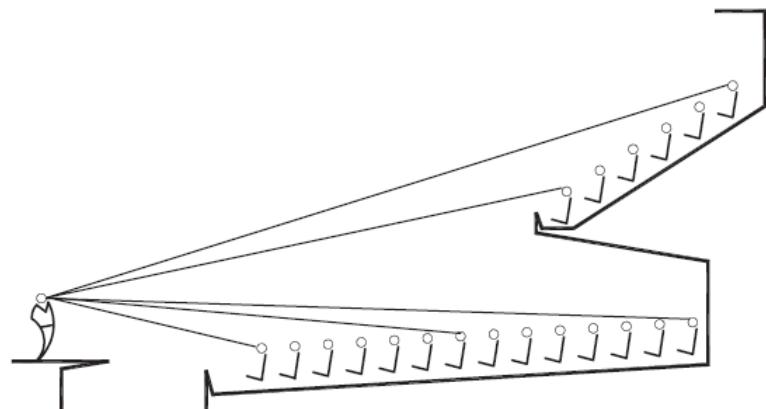
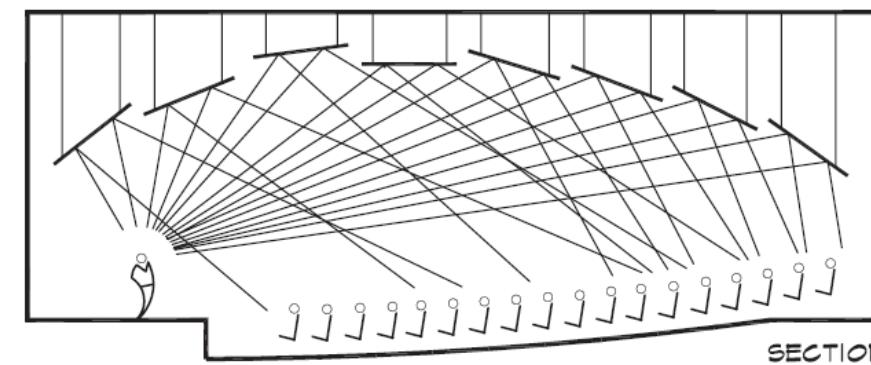
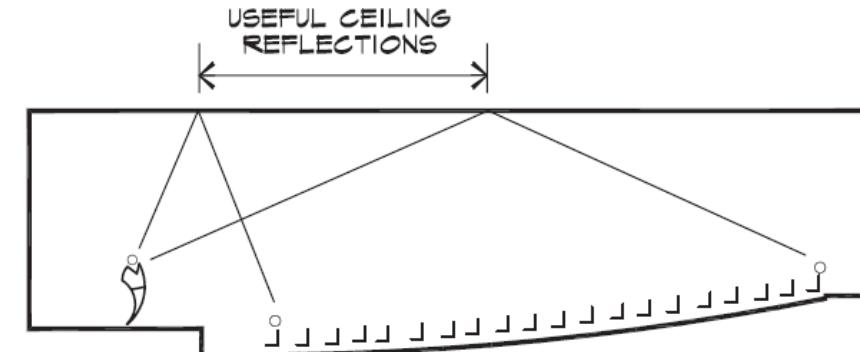
Plan

Auditorium with Balcony



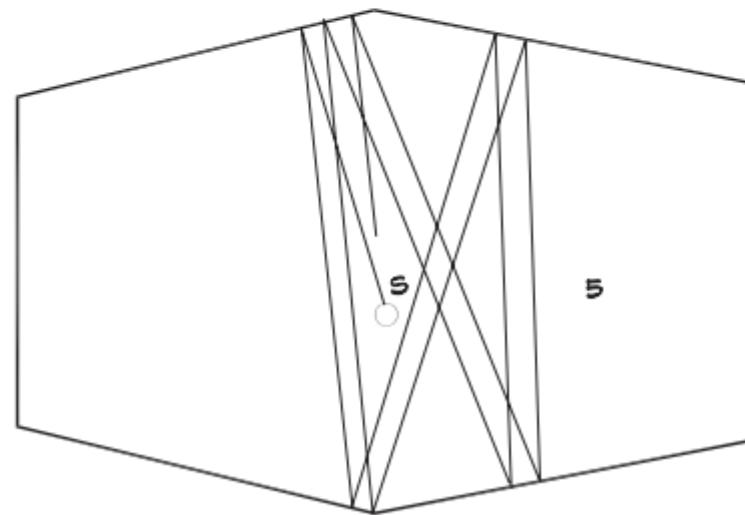
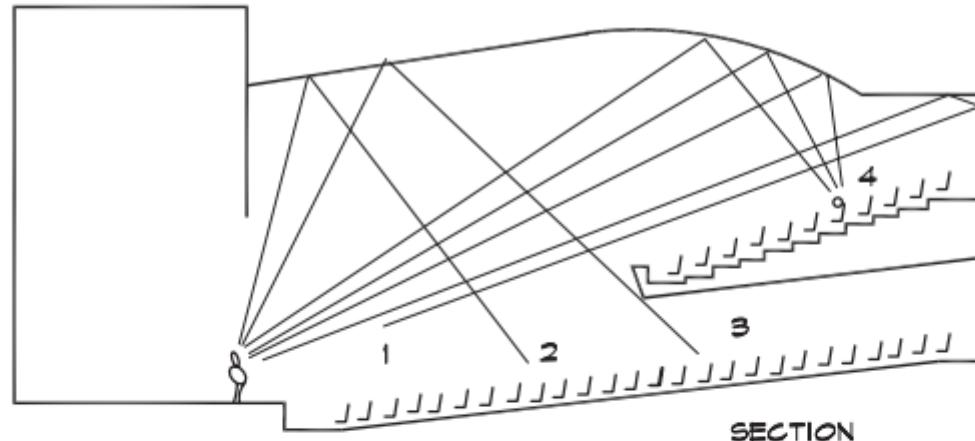
Plan

Auditorium without Balcony





Primjeri loše prakse



- 1) ECHO
- 2) LONG DELAYED REFLECTIONS
- 3) SHADOW ZONE
- 4) FOCUSING
- 5) FLUTTER ECHO

© Marshall Long – Architectural Acoustics, Academic Press 2005.

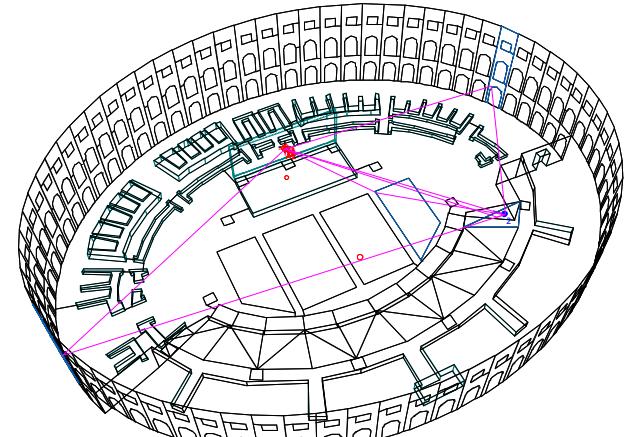
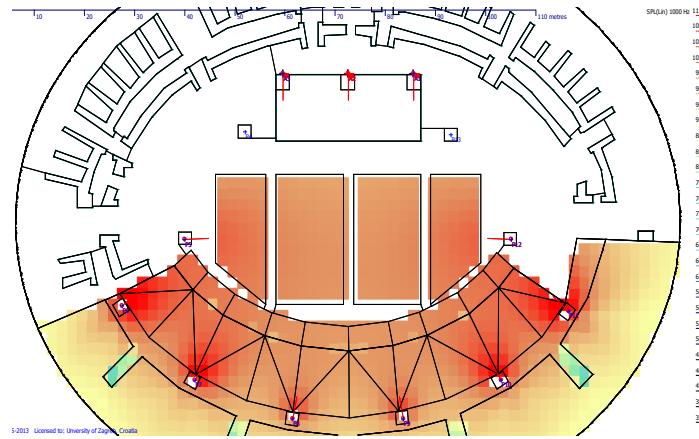
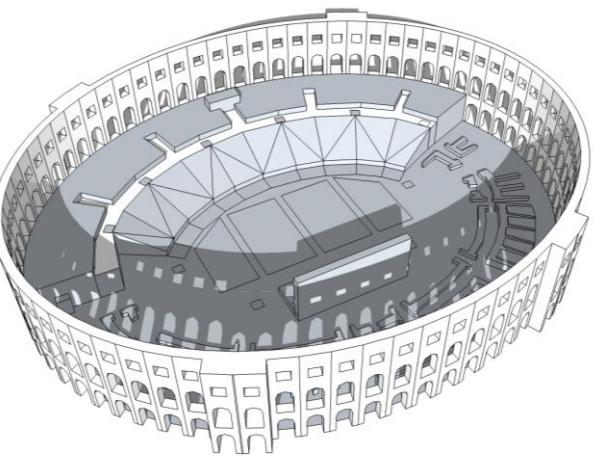
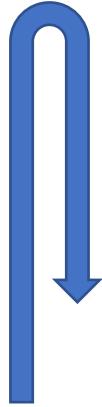
PLAN

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1. Jeka



Odeon©1985-2013 Licensed to: License information /dongle unavailable at start up!

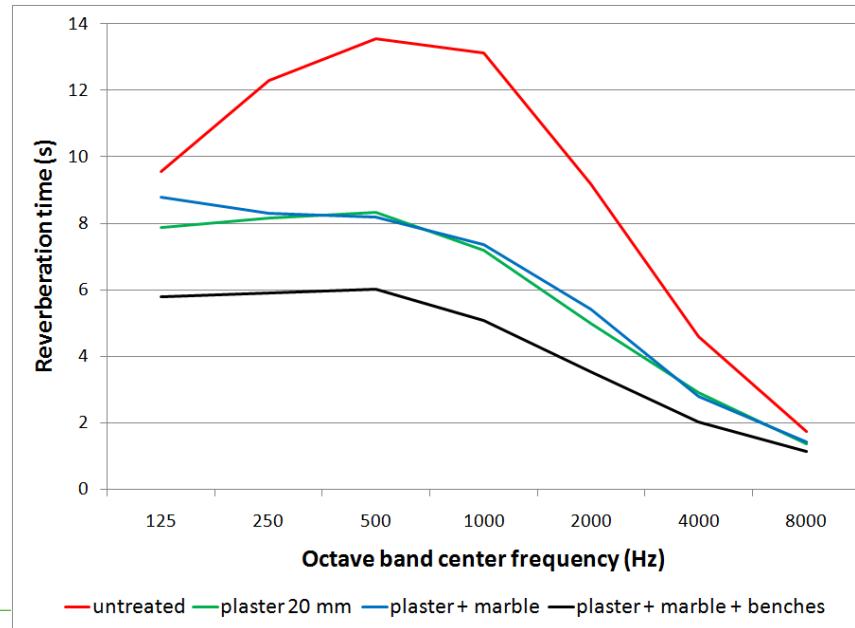
Surface: 2
Surface: 2 "Receiver"
Ref.: 1
Path <m>: 177,98
Time <m>: 519

2. Kasne refleksije

- inicijalno vrijeme odjeka 13,2 s, konačno 6,5 s

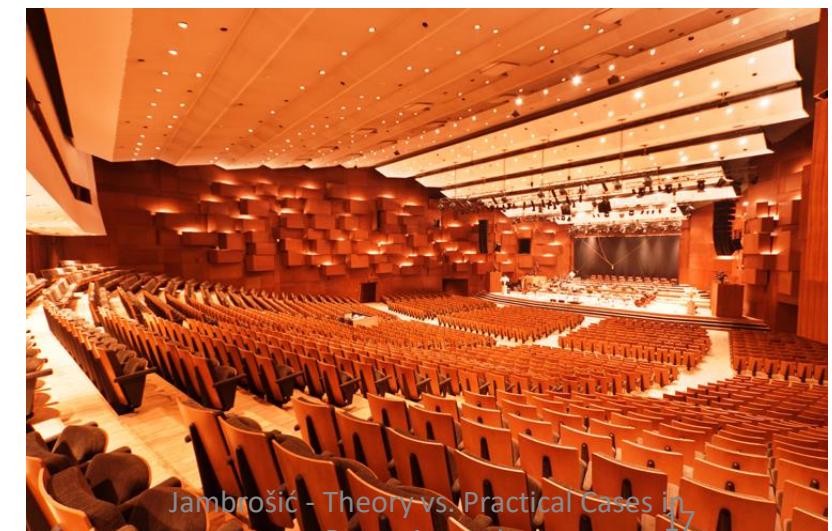
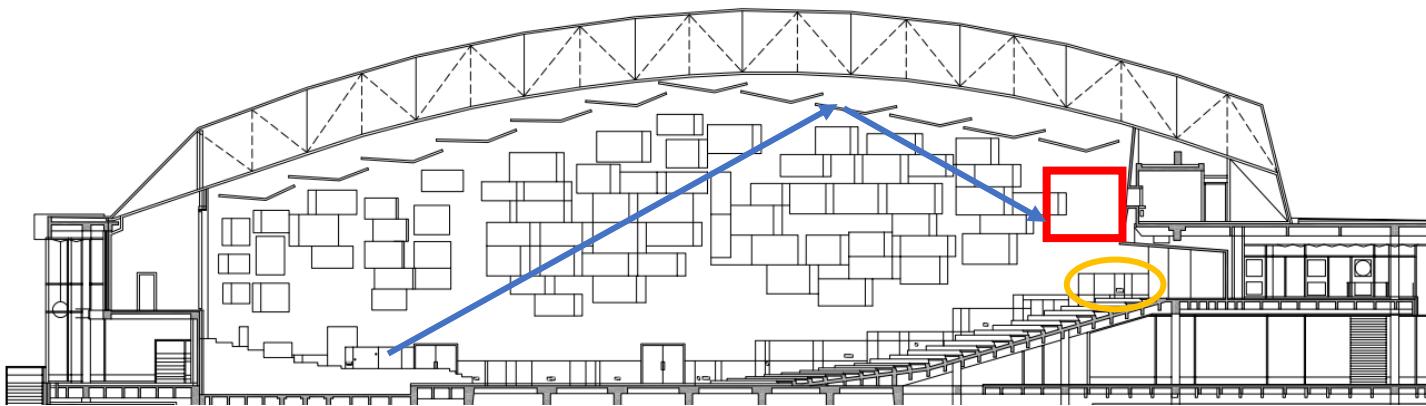


prije





3. Zona sjene



Jambrošić - Theory vs. Practical Cases in
Room Acoustics



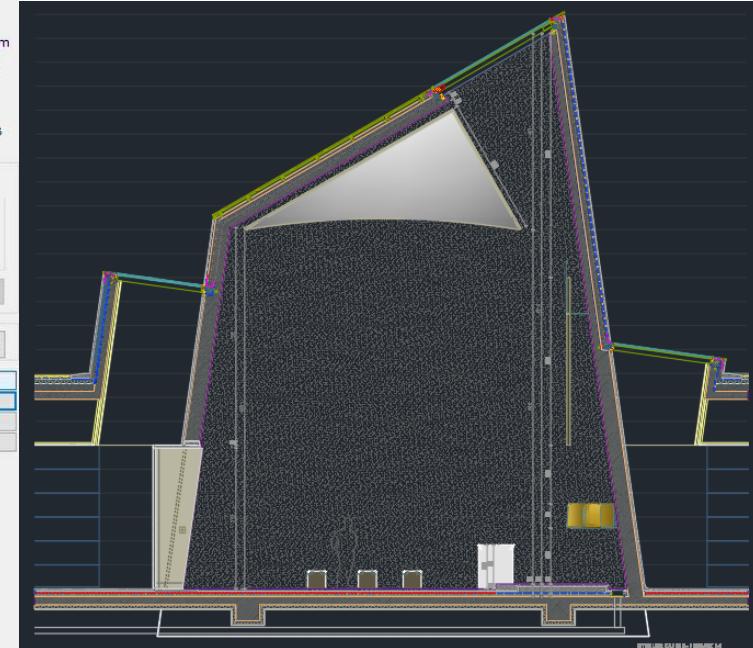
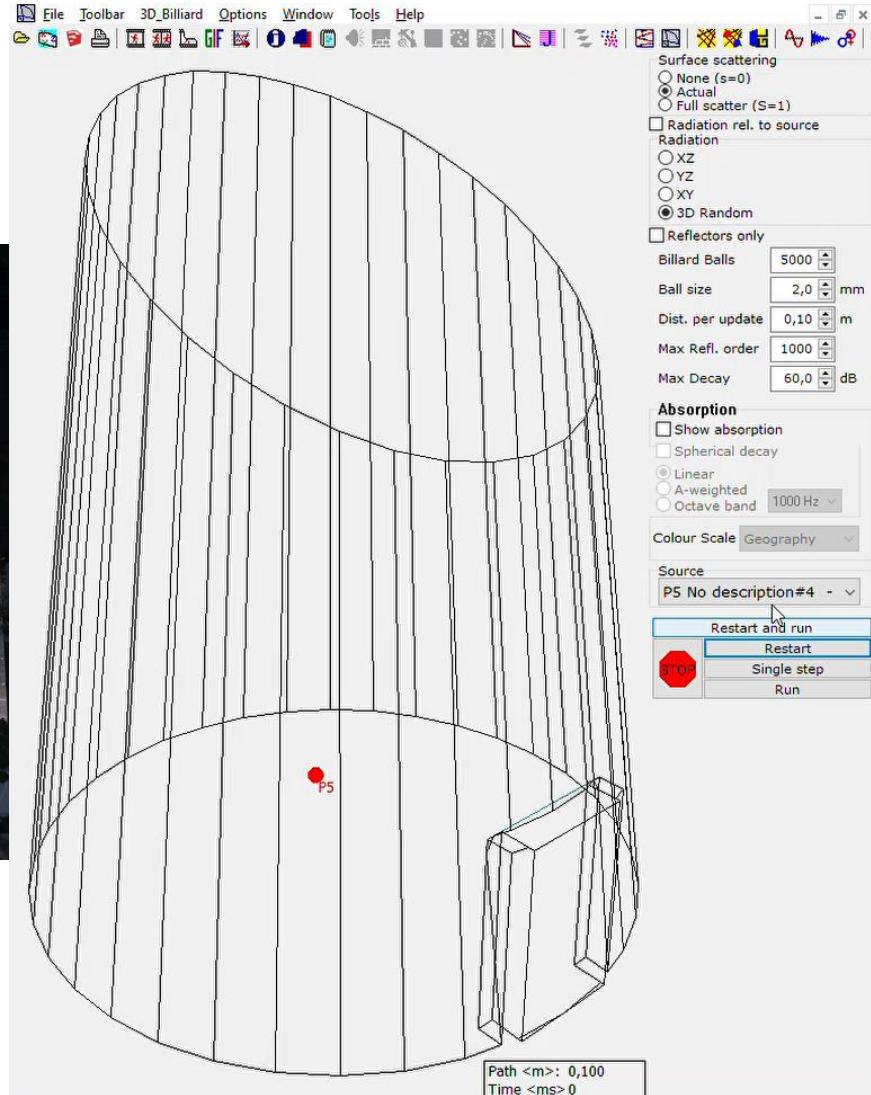
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4. Fokusiranje



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5. Lepršajuća jeka



zelena pozicija



žuta pozicija



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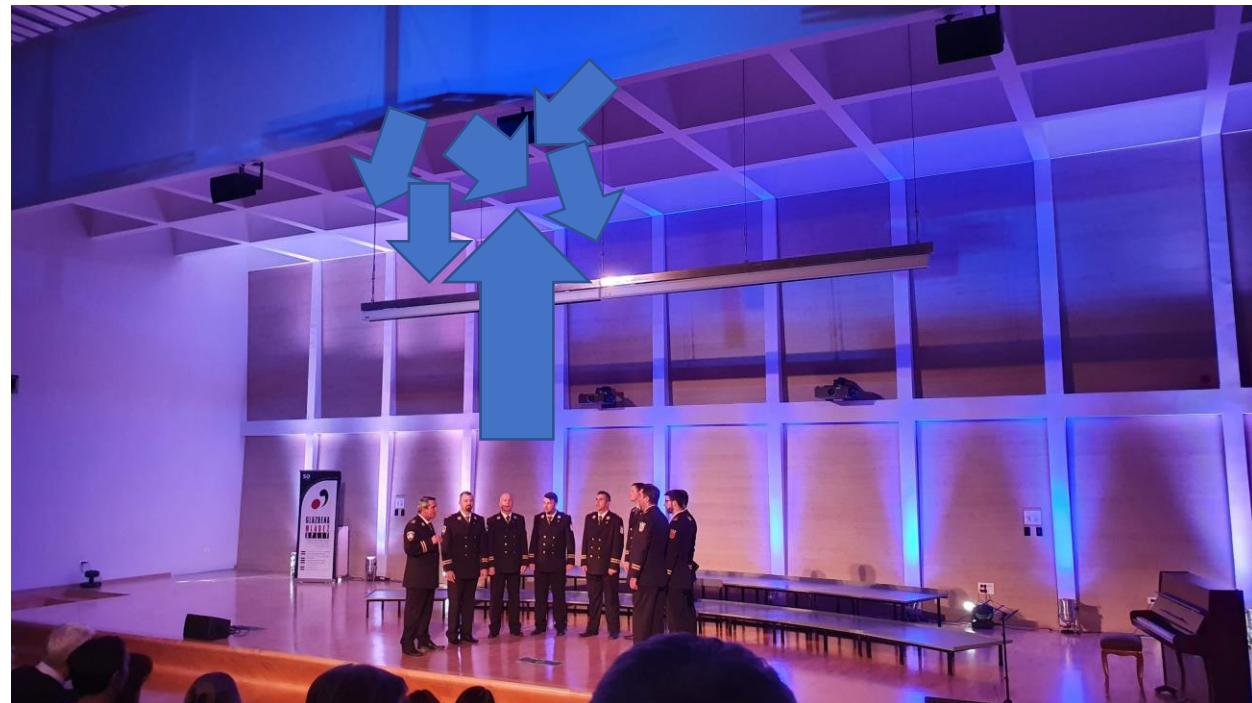
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Preveliko raspršenje



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#1



#2



#3

Crkve 13. do 20. stoljeće

#4



#7



#5



#8



#6



#9



#10



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Crkve 1900. do 1940.



#11



#14



#12



#15



#13



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Crkve 1985. - danas



#16



#20



#24



#17



#21



#25



#18



#22



#26



#19



#23



#27



#28



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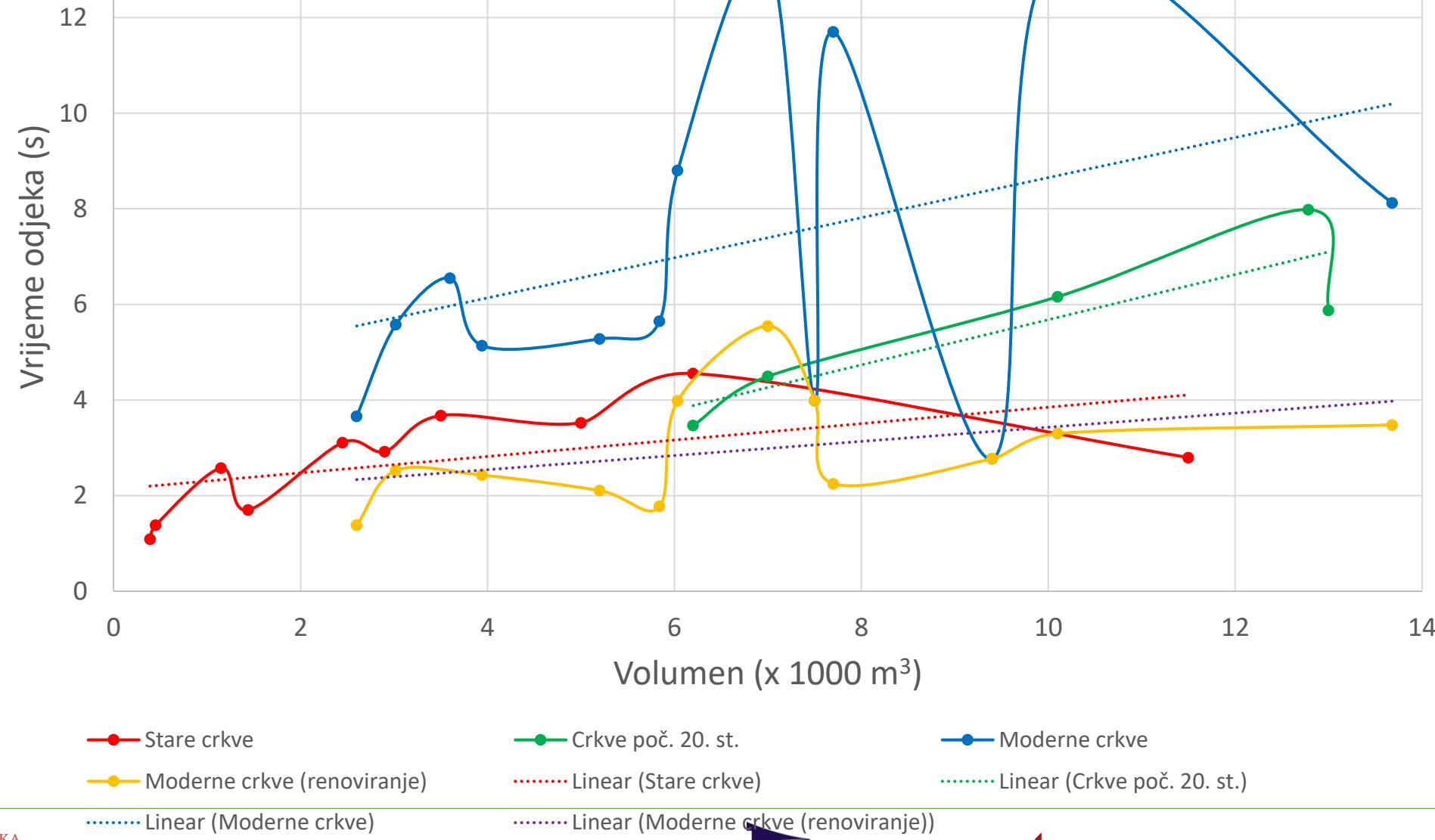
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TROCAL

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INTERNATIONAL PROFILE GROUP
Wienel



Trendovi



—●— Stare crkve

—○— Moderne crkve (renoviranje)

····· Linear (Moderne crkve)

—●— Crkve poč. 20. st.

····· Linear (Stare crkve)

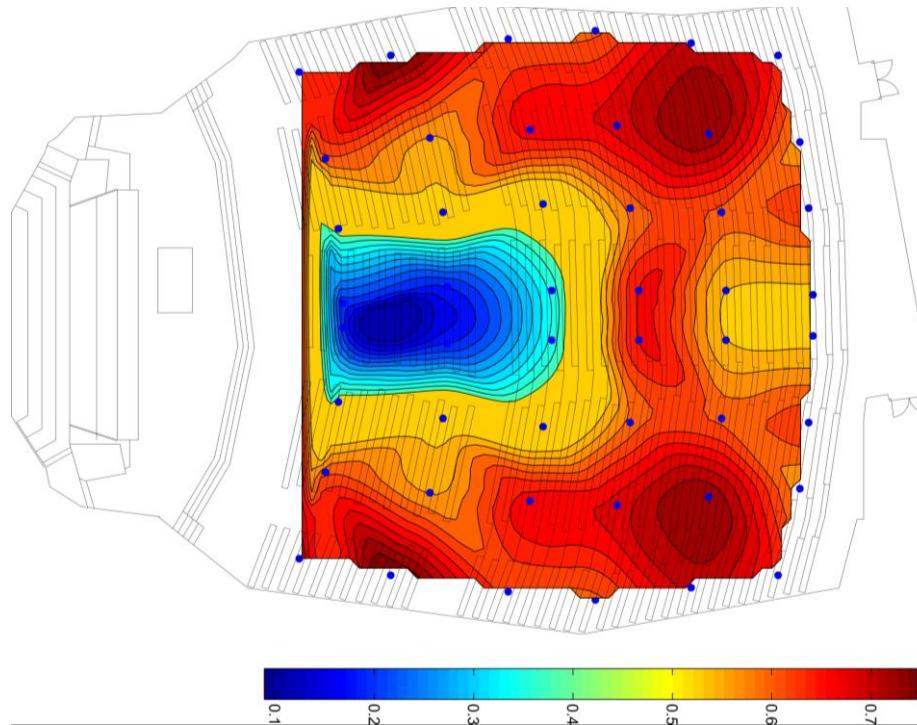
····· Linear (Moderne crkve (renoviranje))

—●— Moderne crkve

····· Linear (Crkve poč. 20. st.)



Vizualizacija parametara



■ indeks binauralne kvalitete (BQI)

Parameter:	s		dB		ms		
	RT_{mid}	EDT_{empty}	BQI	G_{mid}	G_{125}	ITDG	$C_{80,3}$
Conditions:	average			average	125 Hz	center of the hall	average 0,5-1-2 kHz
Symphonic orchestra > 1400 sjedala	0,5-1 kHz			0,5-1 kHz			
Measured hall	1,8 – 2,1	2,2 – 2,6	0,65 – 0,71	1,5 – 5,5	3,0 – 6,0	< 25	-3,0 – 0
	1,80	2,02	0,53	2,3	3,3	24,5	-0,5





Vizualizacija parametara



Akustički parametar	Frekvencija	Tipični raspon	Slanica
Pojačanje G	500 – 1000	-2 dB do +10 dB	4 dB
Vrijeme ranog opadanja zvuka EDT	500 – 1000	1,0 s do 3,0 s	1,2 s
Jasnoća C ₈₀	500 – 1000	-5 dB do +5 dB	1,6 dB
Definiranost D ₅₀	500 – 1000	0,3 do 0,7	0,43



Slanica Concert Hall	RT ₆₀ (s)	EDT (s)	BQI	G _{mid} (dB)	C ₈₀ (dB)	ITDG (ms)	V/N (m ³ /pers.)	STI
Measured values	1.20	1.20	0.72	5.7	1.6	3.74	4.0	0.56
Symphonical music								
Chamber music								
Opera								
Speech								
Cinema								

Af



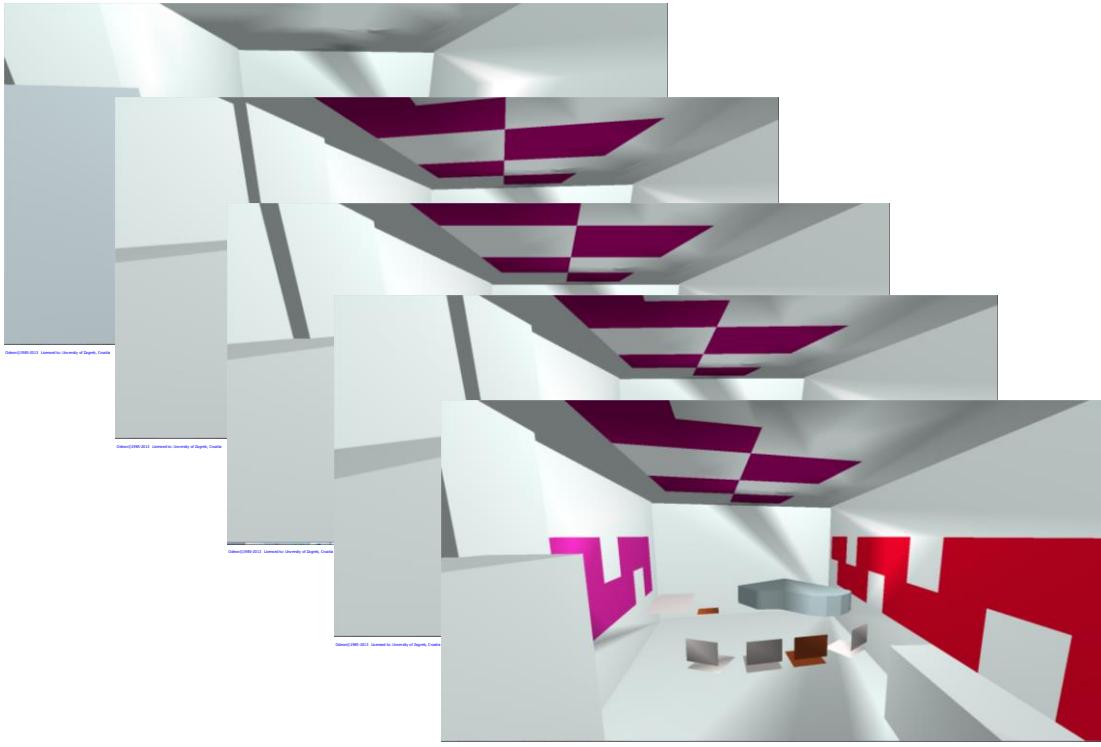
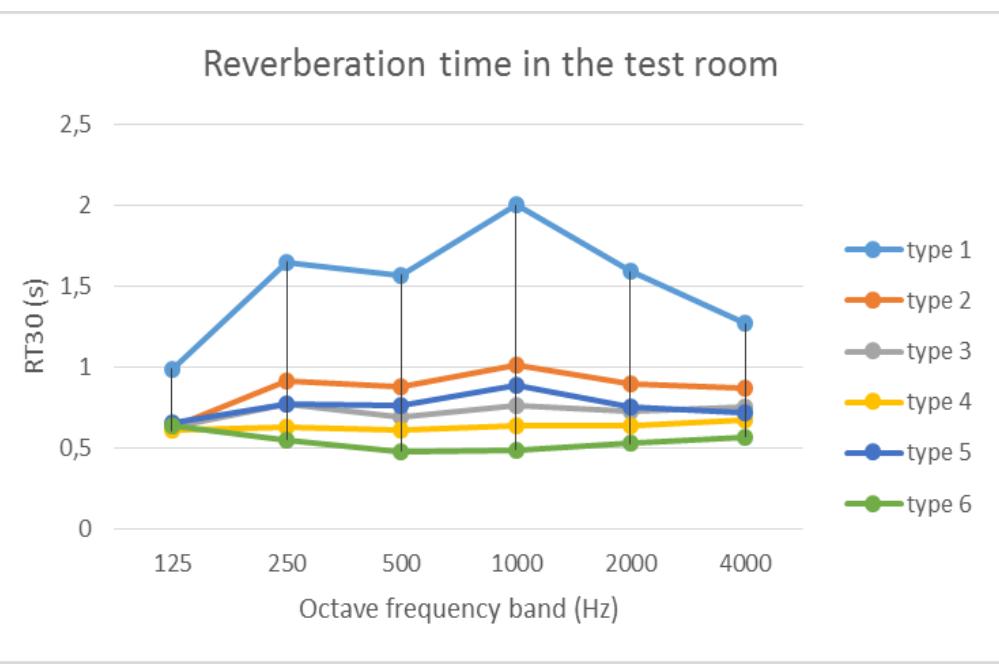
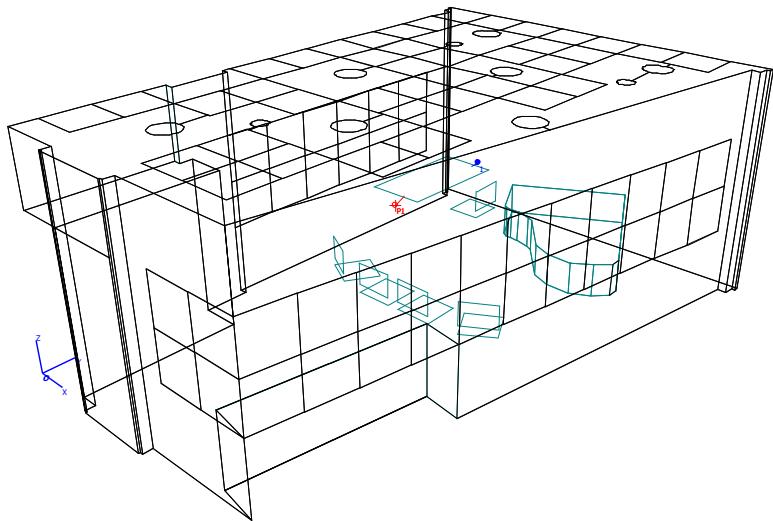
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Auralizacija prostora





Auralizacija prostora



1,5 s



0,5 s





Zaključak

- akustička ugoda / komfor jedan od ključnih značajki prostora, posebno tada gdje je razumljivost govora, kvaliteta glazbe ili niska razina šuma ključna
- prostorna akustika je kompleksna disciplina i lako je „promašiti“ akustički dizajn prostorije ako se radi nestručno i „od oka“
- akustički defekti su čujni i često smanjuju upotrebljivost nekog prostora
- elaborati prostorne akustike mogu biti lakše razumljivi i laicima ako se upotrijebe metode vizualizacije ključnih parametara, ili auralizacija zvuka

Af



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