Concert Halls and Opera Houses: how to make them sound. *The use of parametric design tools in room acoustics*

14. DEGA-Symposium
"Interaktive Auralisierung für die Planung von Räumen"
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Some Concert Halls…

Musikverein Vienna

KKL Luzern

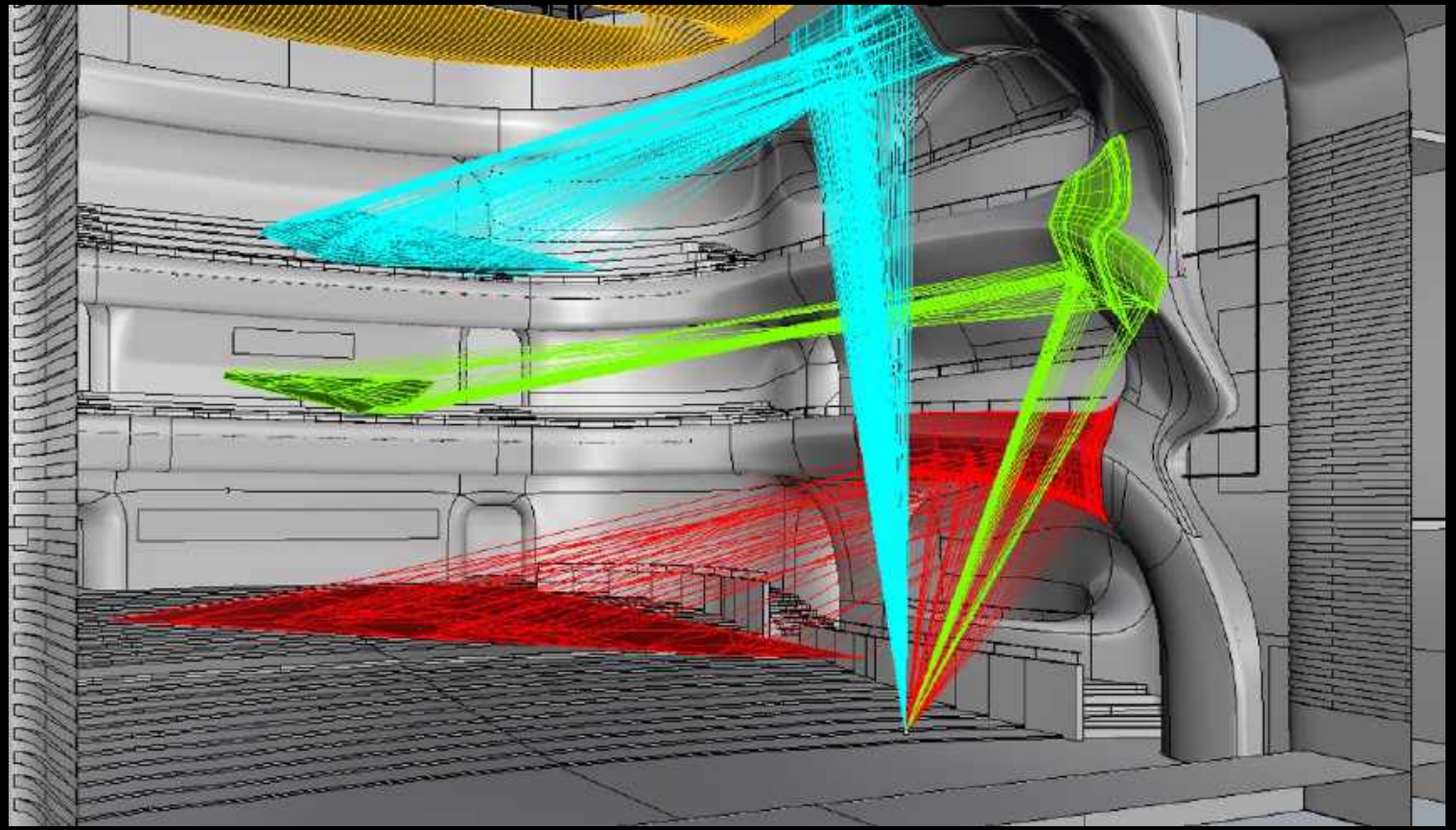
Stavanger Fartein Valen Concert Hall

Stavanger Fartein Valen Concert Hall

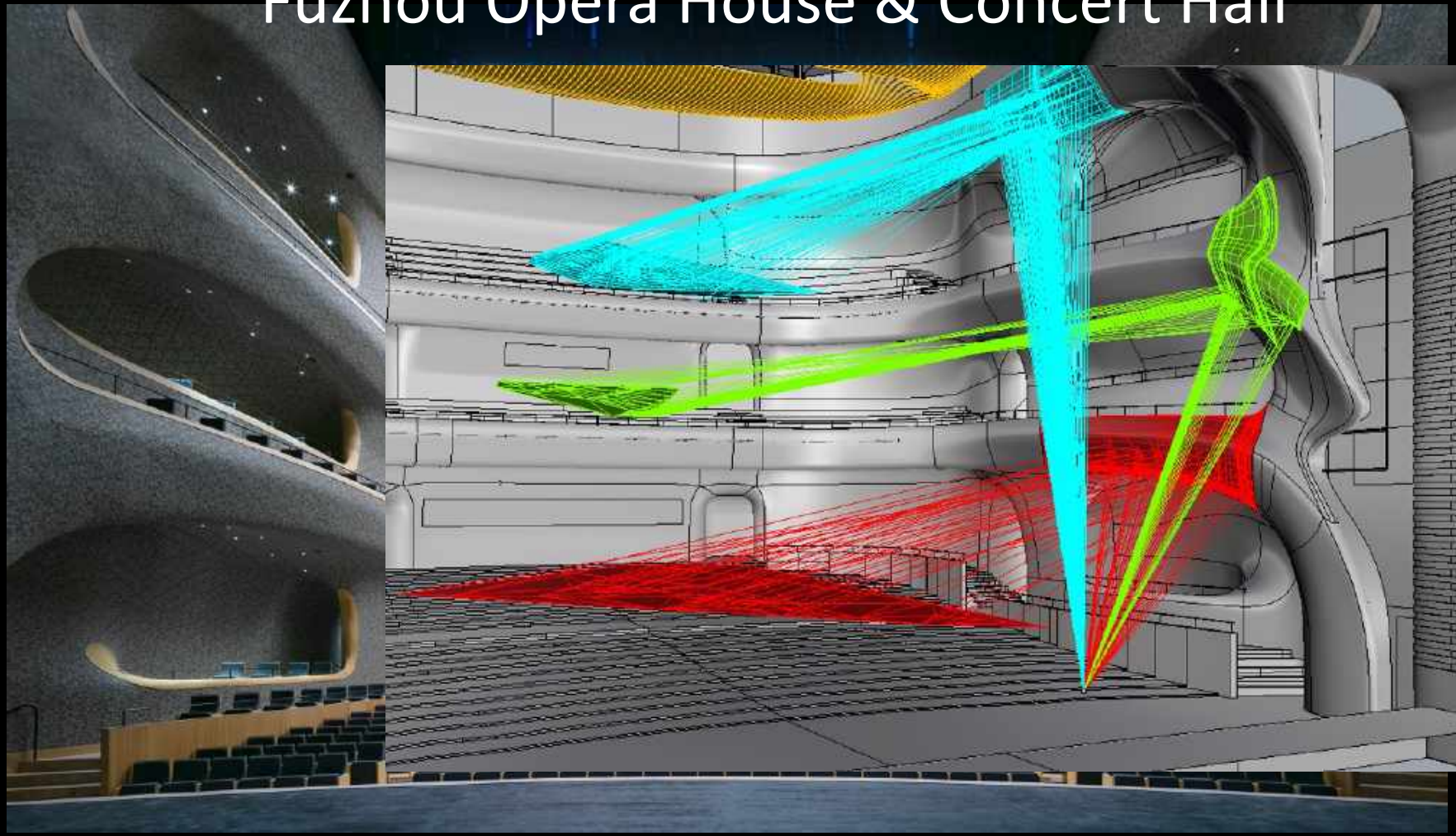
Philharmonie de Paris

Fuzhou Opera House & Concert Hall

Fuzhou Opera House & Concert Hall



Fuzhou Opera House & Concert Hall



Fuzhou Opera House & Concert Hall

Why do we optimize reflection coverage?

1. *Because we have to…! (WC Sabine already indicated this…)*
2. *To increase the "kit" of potential solutions…!*
3. *Curved surfaces…!*
4. *Because every concert hall and architectural design is different… – and should be different…!*
5. *To get away from the "shoebox or vineyard" typology paradigm, there are a lot of interesting options in between…!*
6. *Avoid errors and find problems before they are built…!*
7. *It is fun…!*

Why do we optimize reflection coverage?

1. Because we have to…!

Wallace Clement Sabine (*"Reverberation",* 1900):

In order that hearing may be good..., it is necessary that the sound should be sufficiently loud; that the simultaneous components of a complex sound should maintain their proper relative intensities; and that the successive sounds in rapidly moving articulation, either of speech or music, should be clear and distinct, free from each other and from extraneous noises.

Which means:

1. *Loudness.*
2. *Distortion of Complex Sounds: Interference and Resonance.*
3. *Confusion: Reverberation, Echo and Extraneous Sounds.*

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Requirements for symphony concert halls:

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Life is tough... or life is fun, finding/creating these multiple reflections!

2 – Increasing the tool kit

The Sage (UK) – Shoebox Concert Hall

2 – Increasing the tool kit

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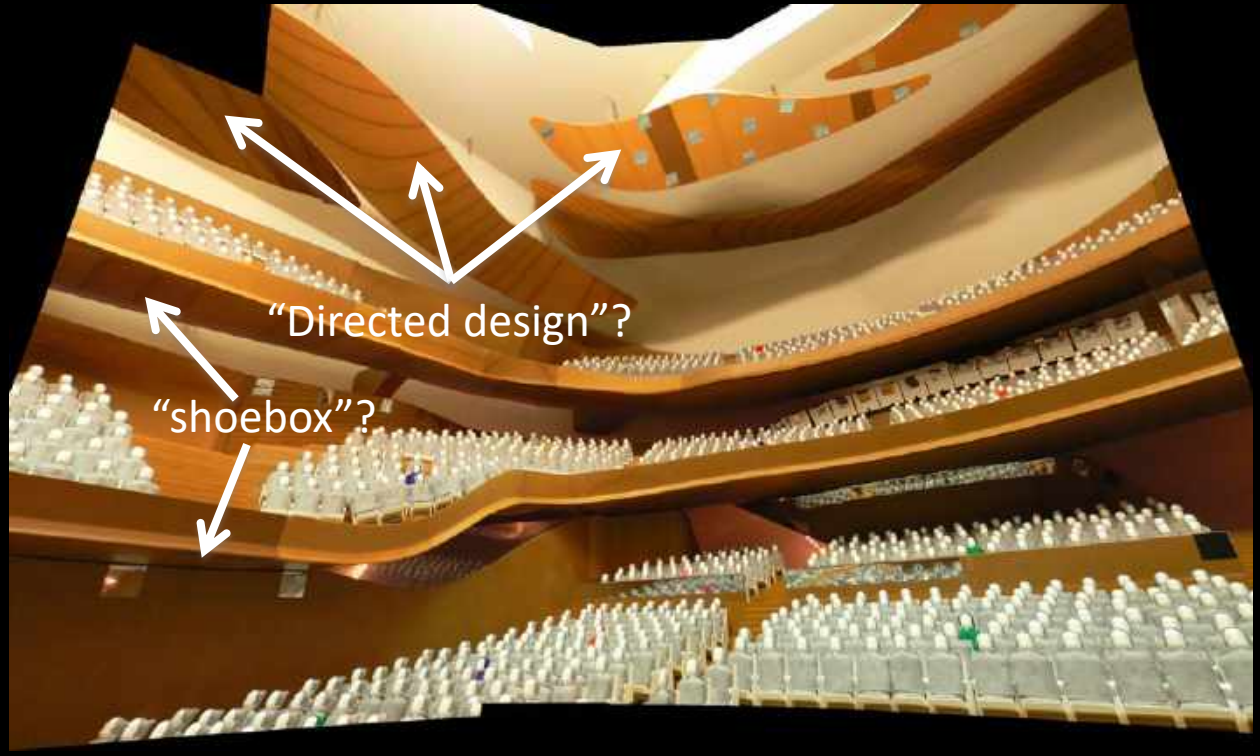
2 – Increasing the tool kit

Philharmonie Paris - Vineyard

2 – Increasing the tool kit

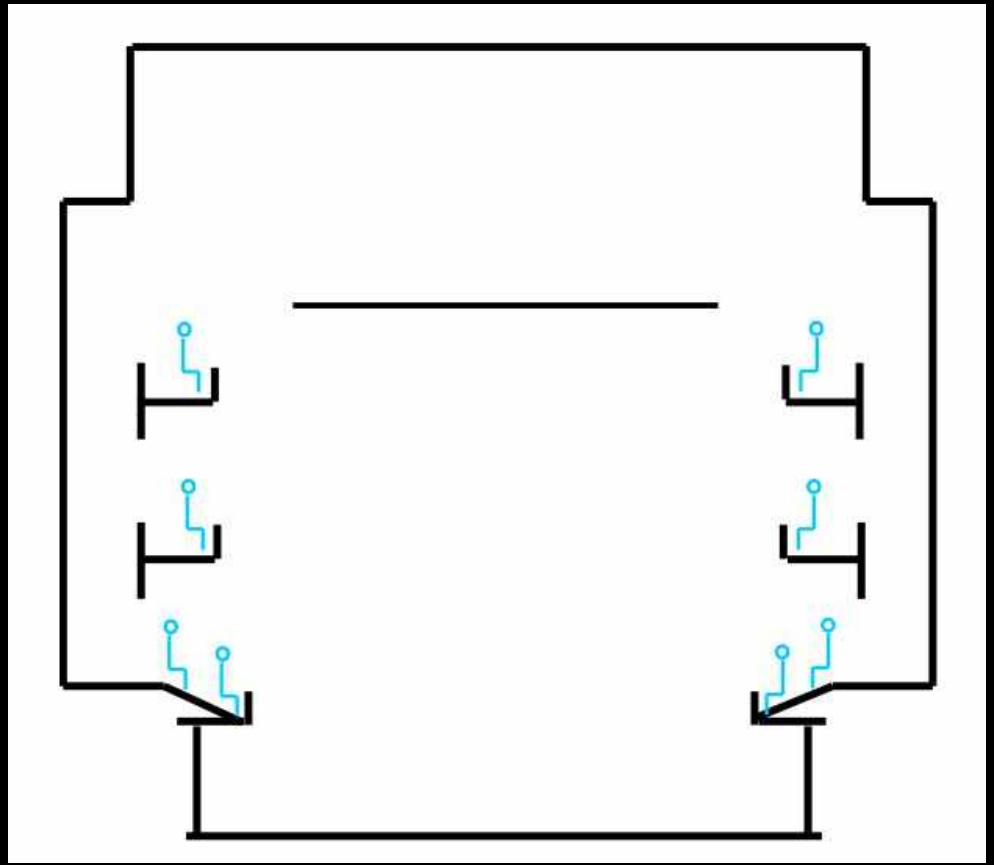


Philharmonie Paris – 1:10 acoustic scale model

2 – Increasing the tool kit

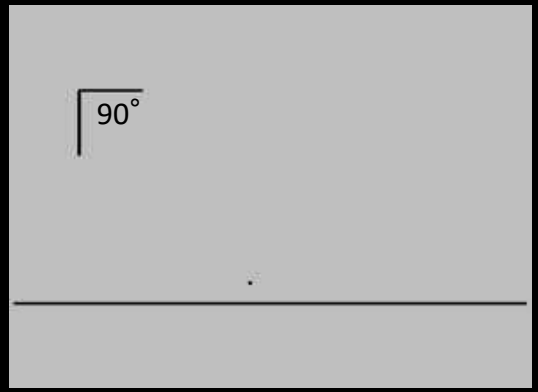
Stavanger Concert Hall

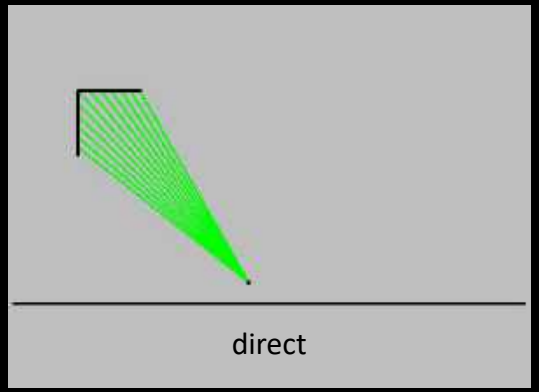
2 – Increasing the tool kit – balcony undersides

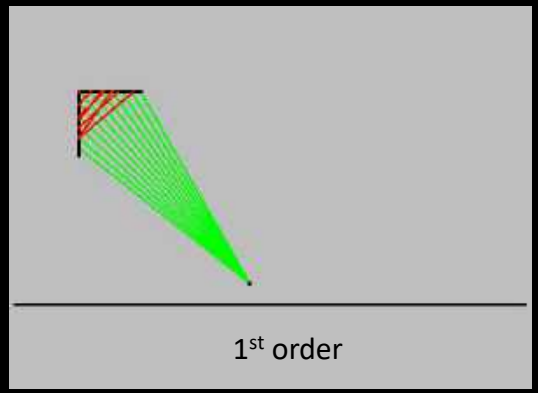


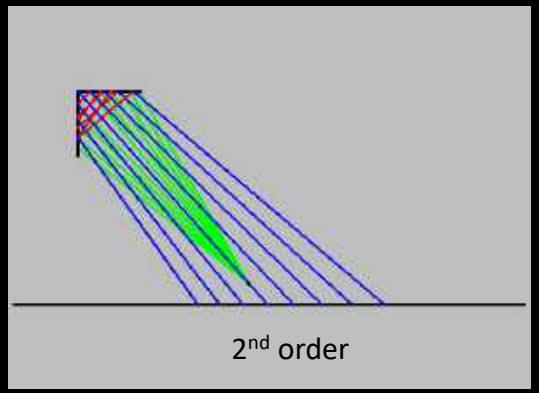
Stavanger floating balconies with downstands

2 – Increasing the tool kit – balcony undersides



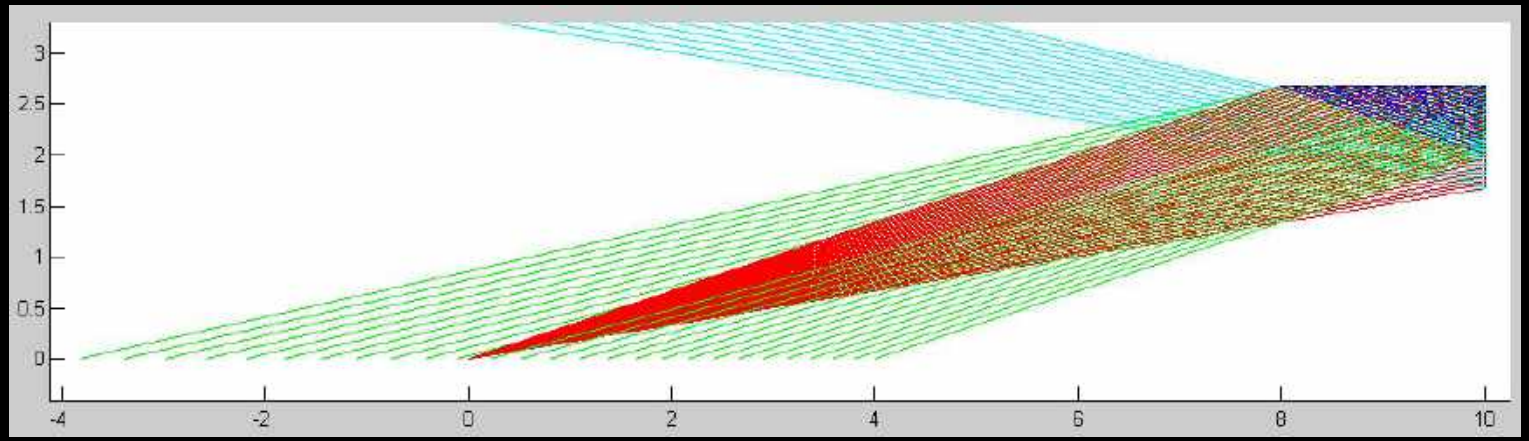






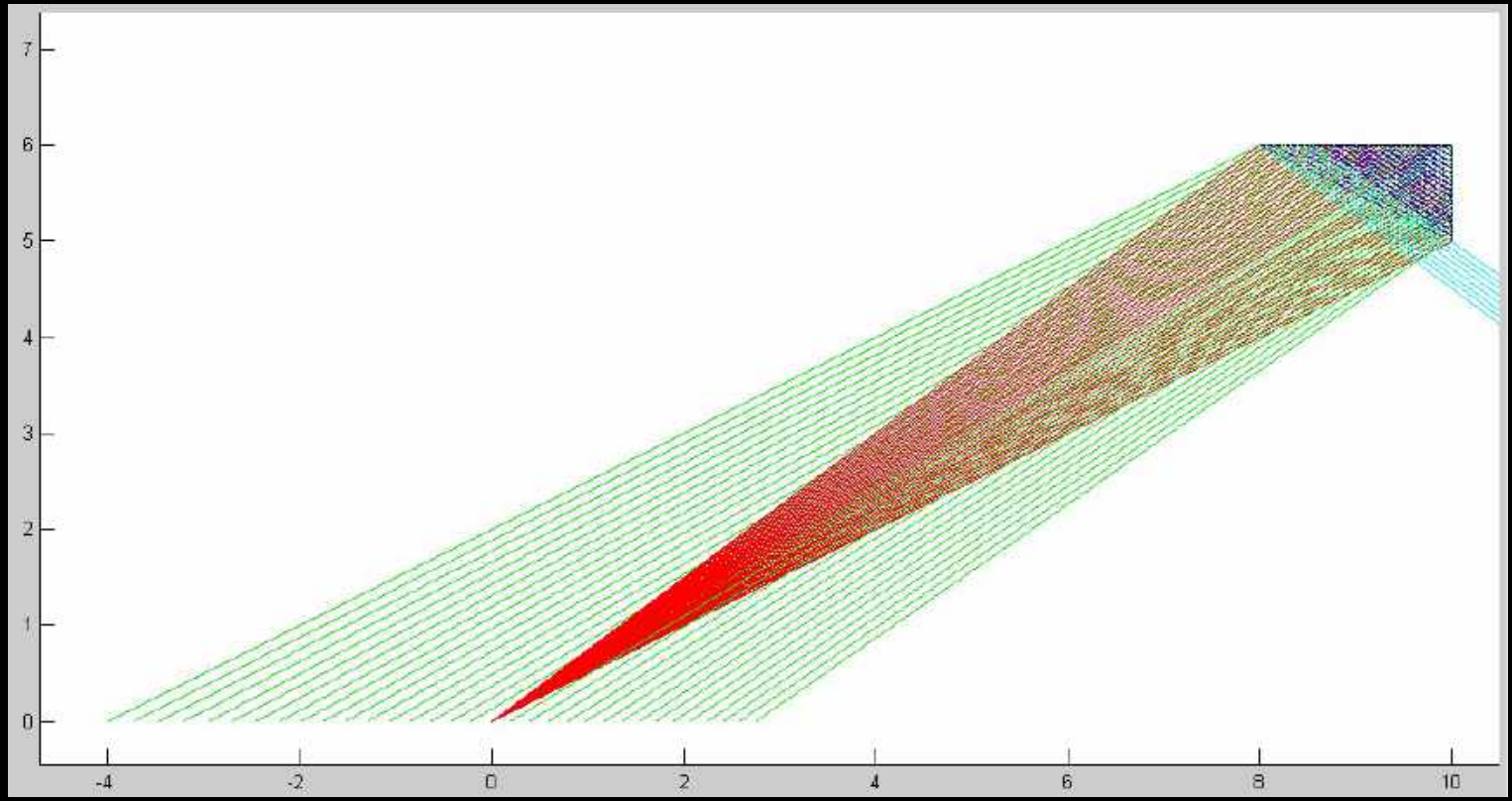
Principle of functioning of shoe-box

2 – Increasing the tool kit – balcony undersides



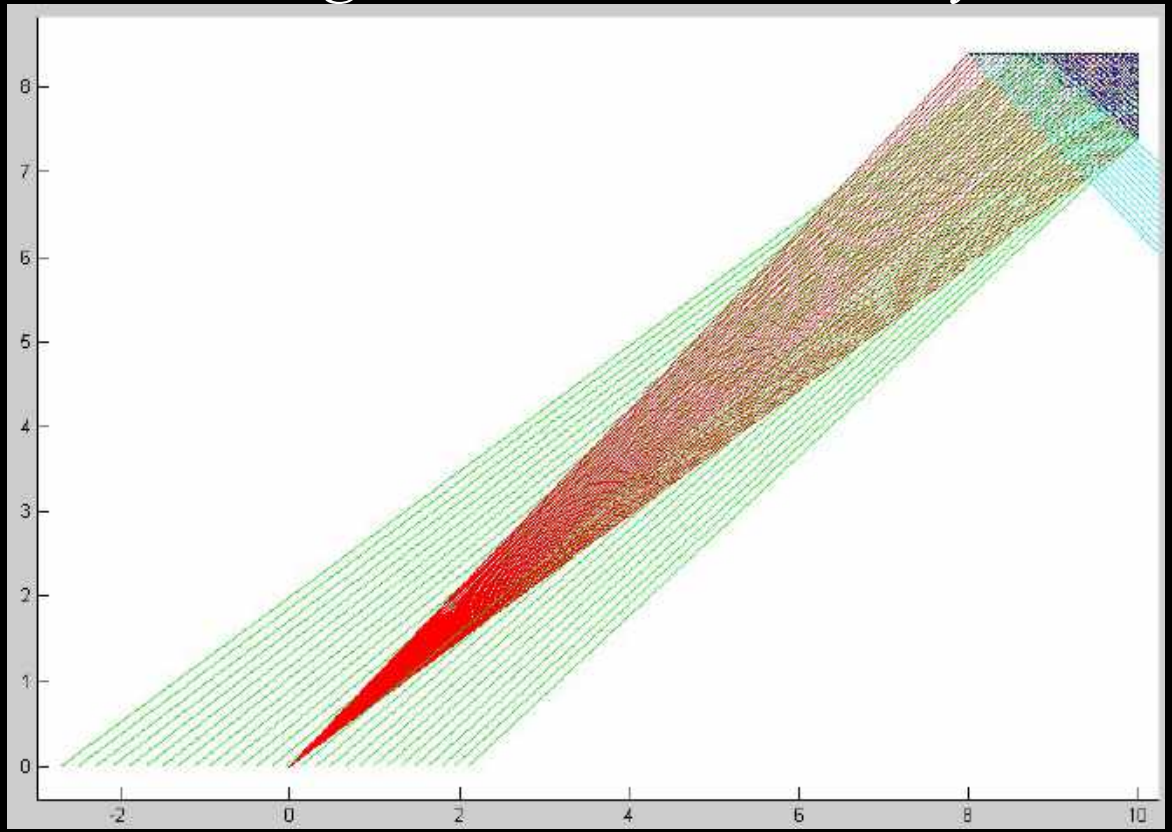
Lower side balcony: angle 15° , coverage [-4 ; 4]

2 – Increasing the tool kit – balcony undersides



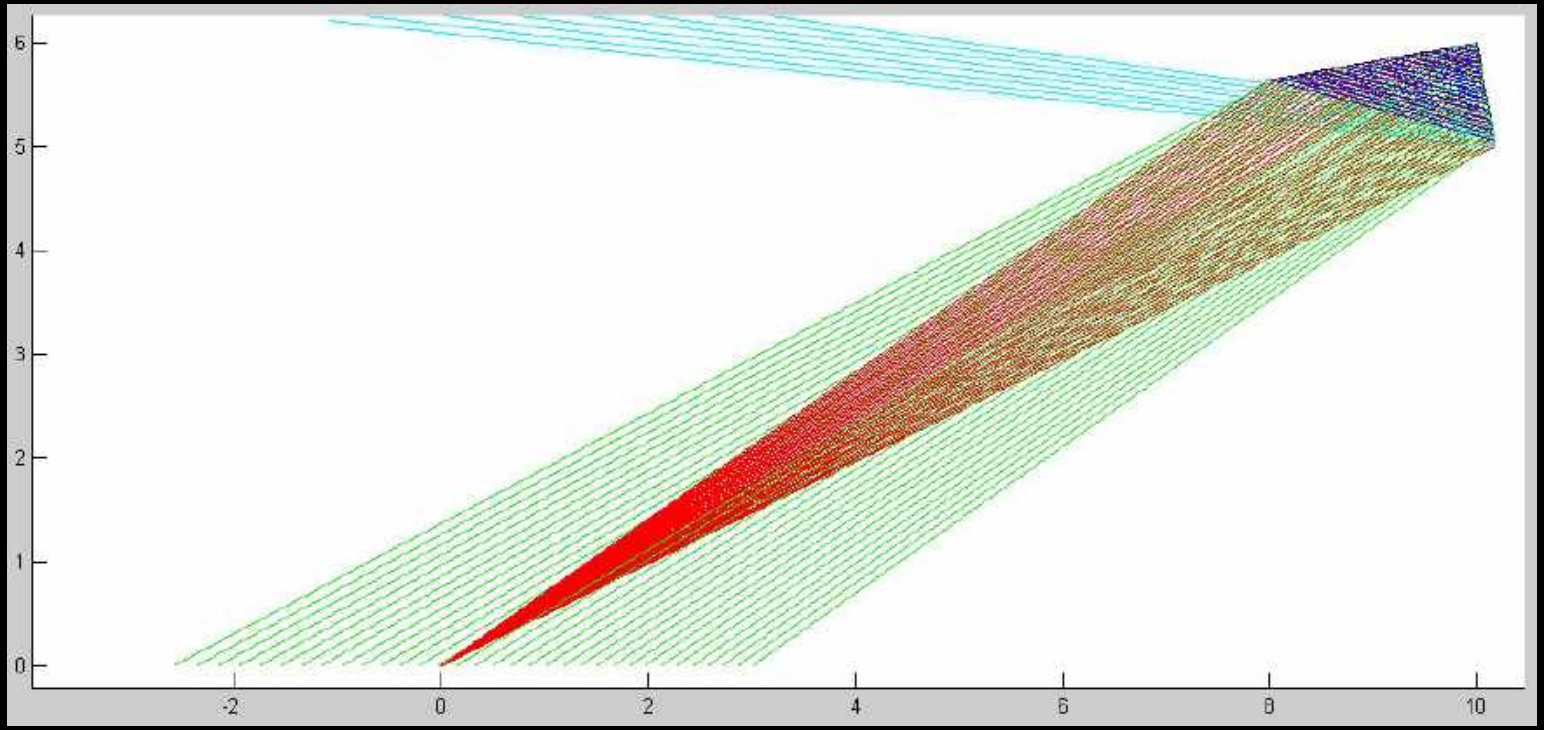
Middle side balcony: angle 26° , coverage [-4 ; 2.5]

2 – Increasing the tool kit – balcony undersides



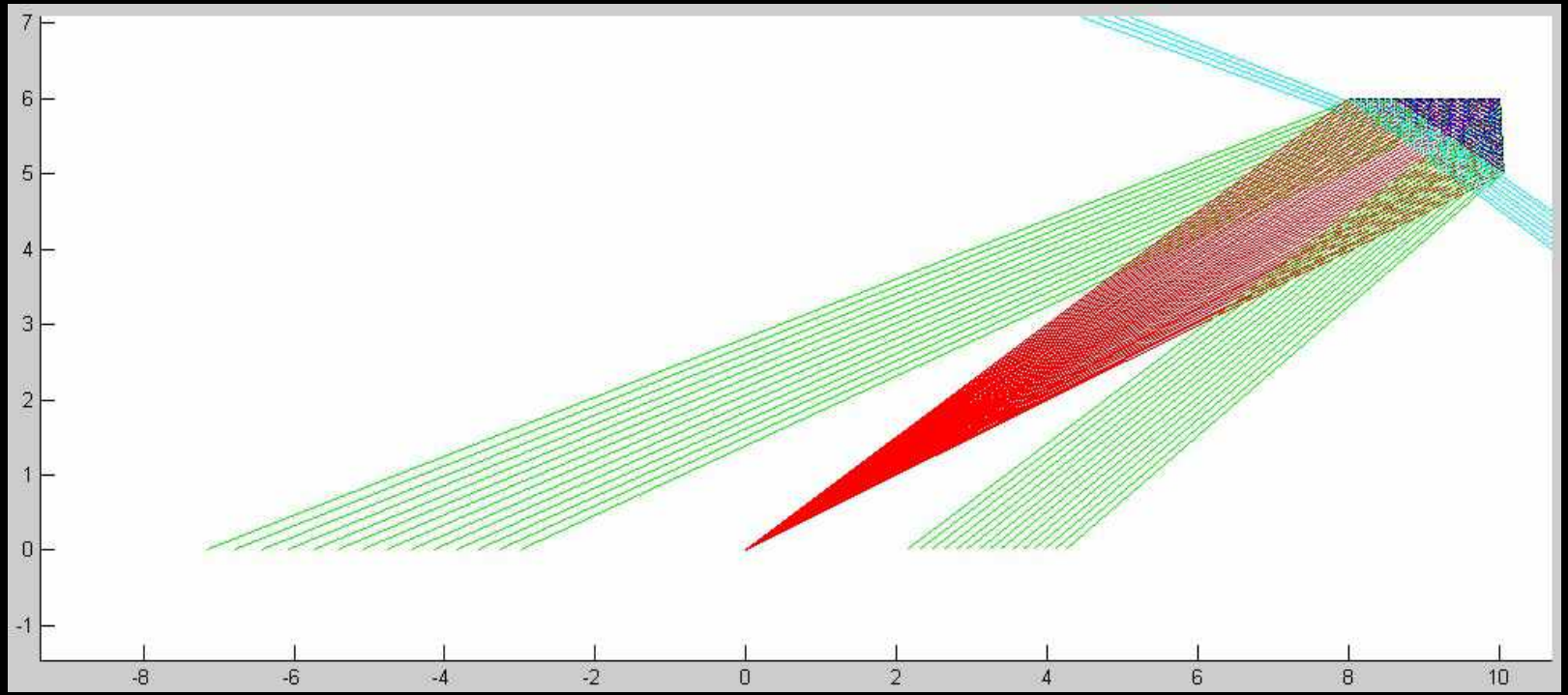
Upper side balcony: angle 40° , coverage [-3 ; 2]

2 – Increasing the tool kit – balcony undersides



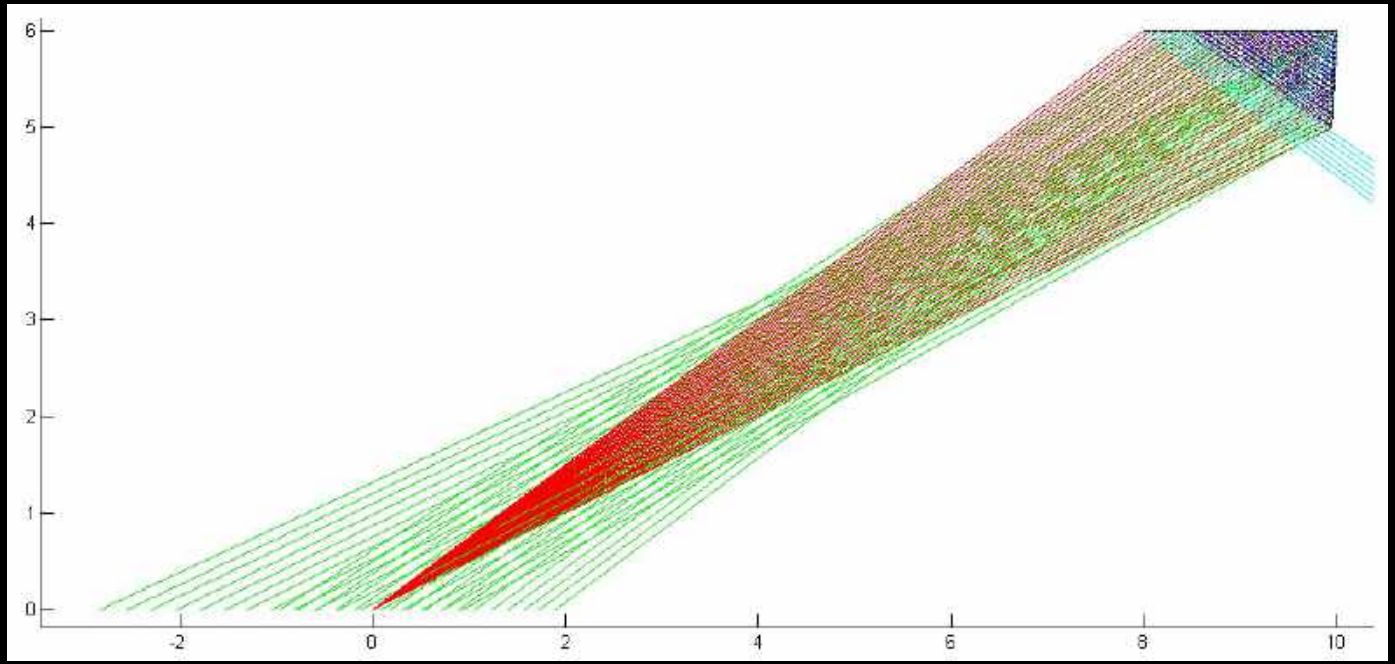
Middle side balcony: angle 10° , coverage [-2.5 ; 3]

2 – Increasing the tool kit – balcony undersides



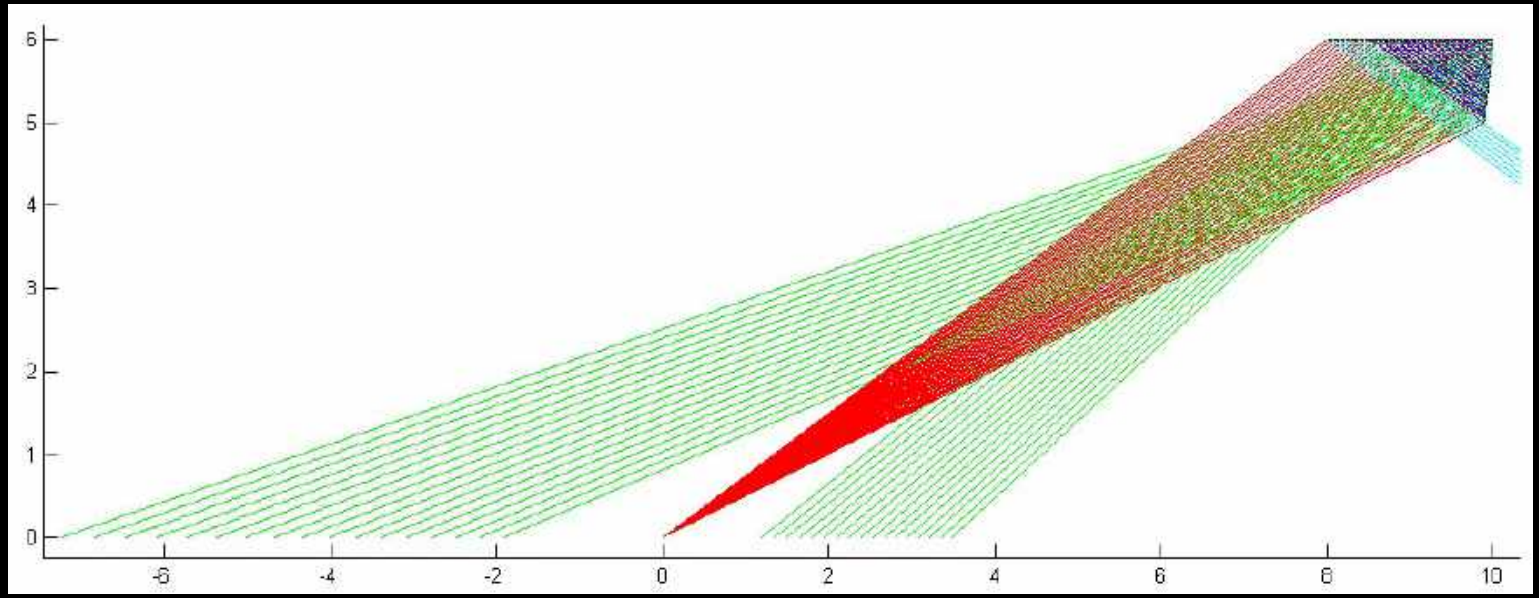
Middle side balcony: angle 93˚

2 – Increasing the tool kit – balcony undersides



Middle side balcony: angle 87˚

2 – Increasing the tool kit – balcony undersides



Middle side balcony: angle 84˚

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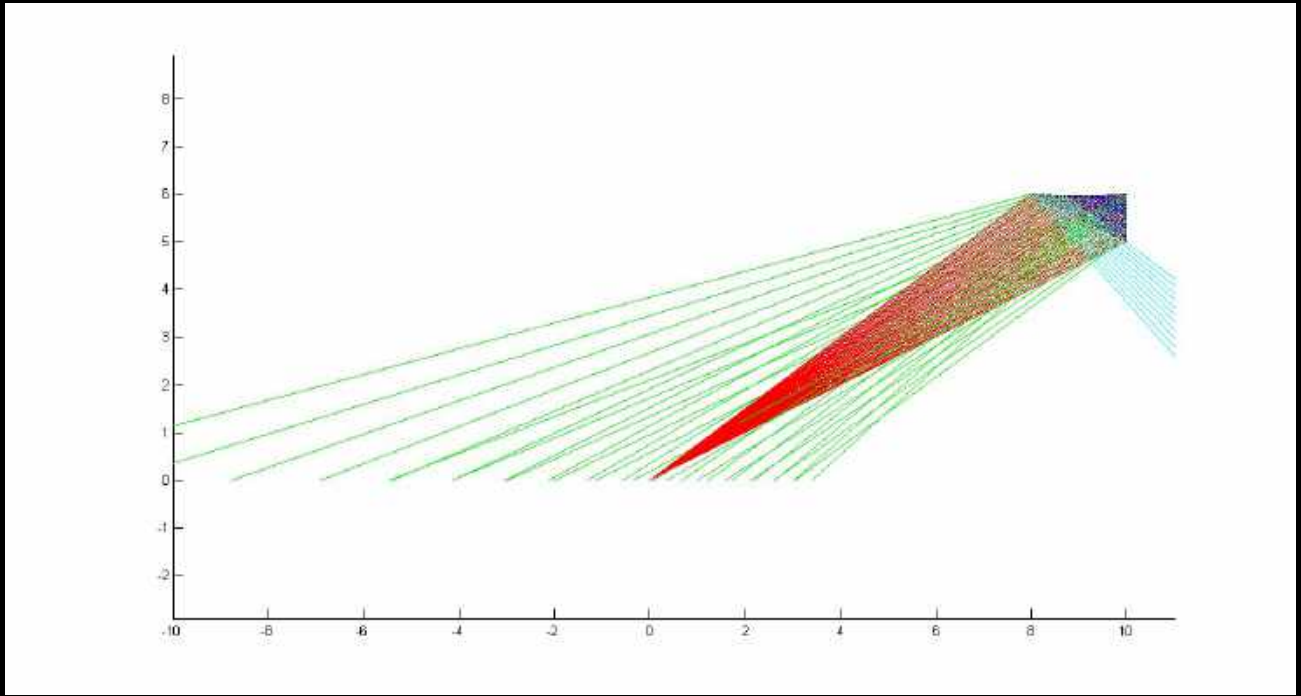
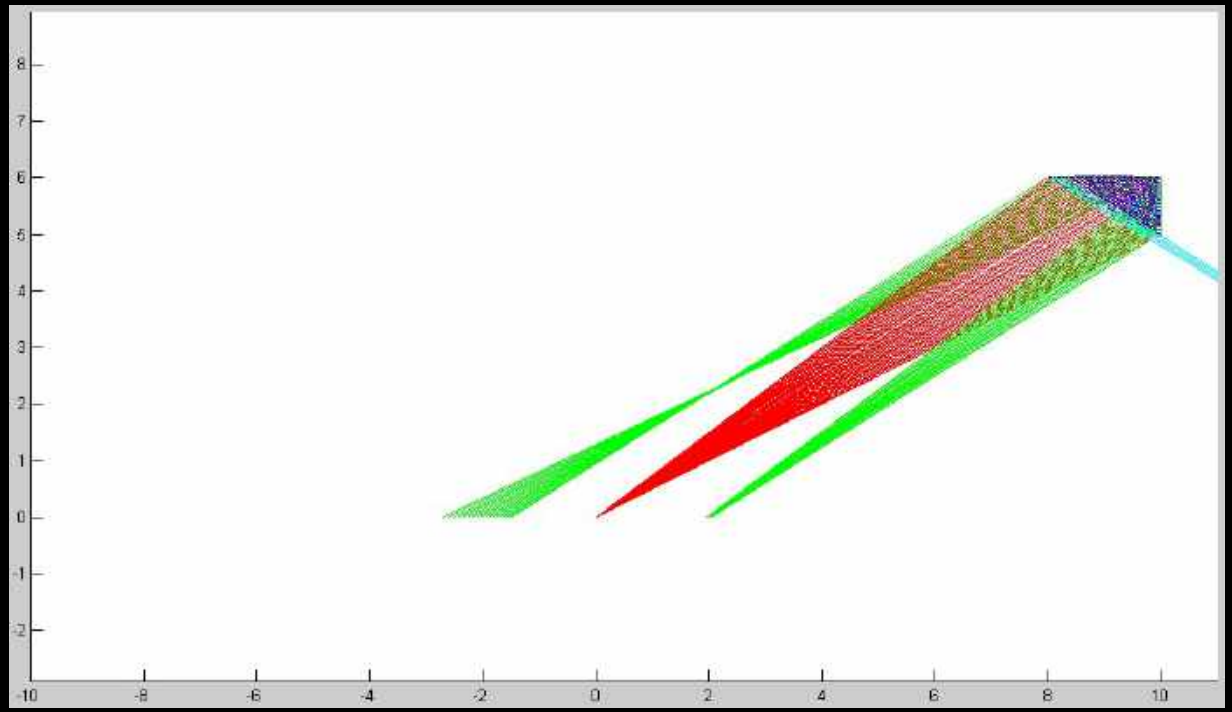


Convex curved (R=20m): better coverage but losses…

2 – Increasing the tool kit – balcony undersides



Concave curved (R=20m): less coverage and dangerous focusing close to audience plane…

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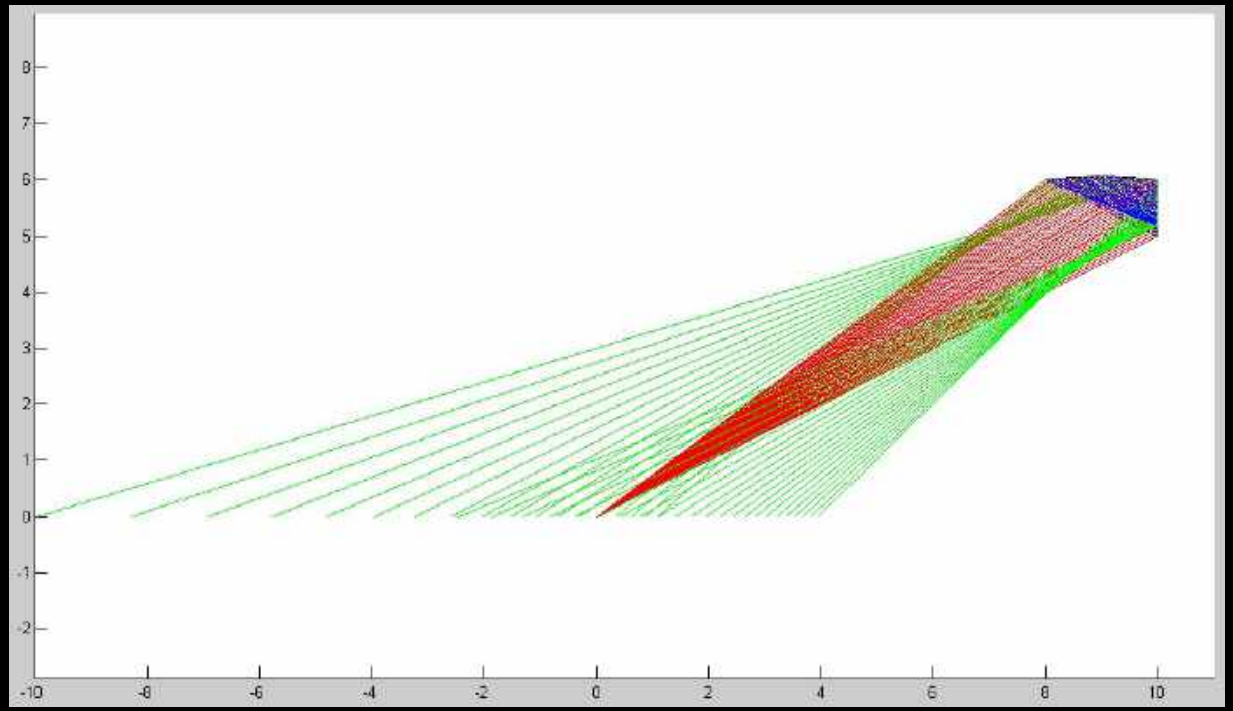
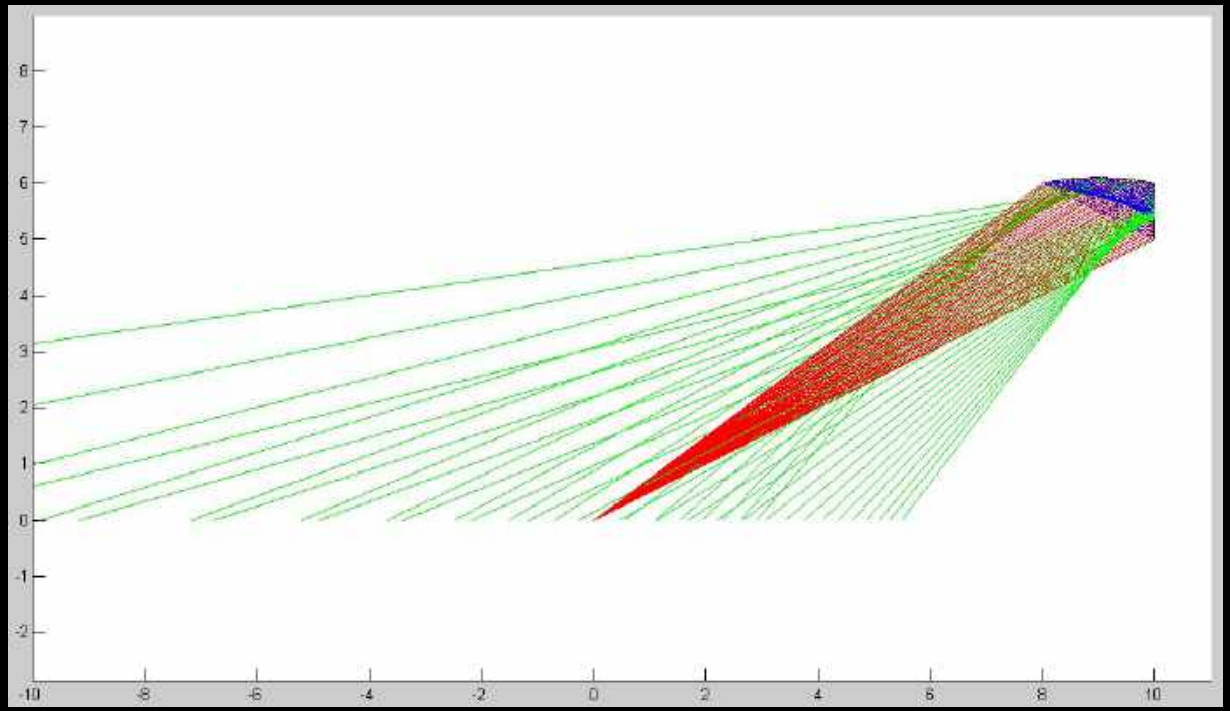


Concave curved (R=8m): much more coverage and some overlapping…

2 – Increasing the tool kit – balcony undersides



Concave curved (R=5m): very wide coverage!

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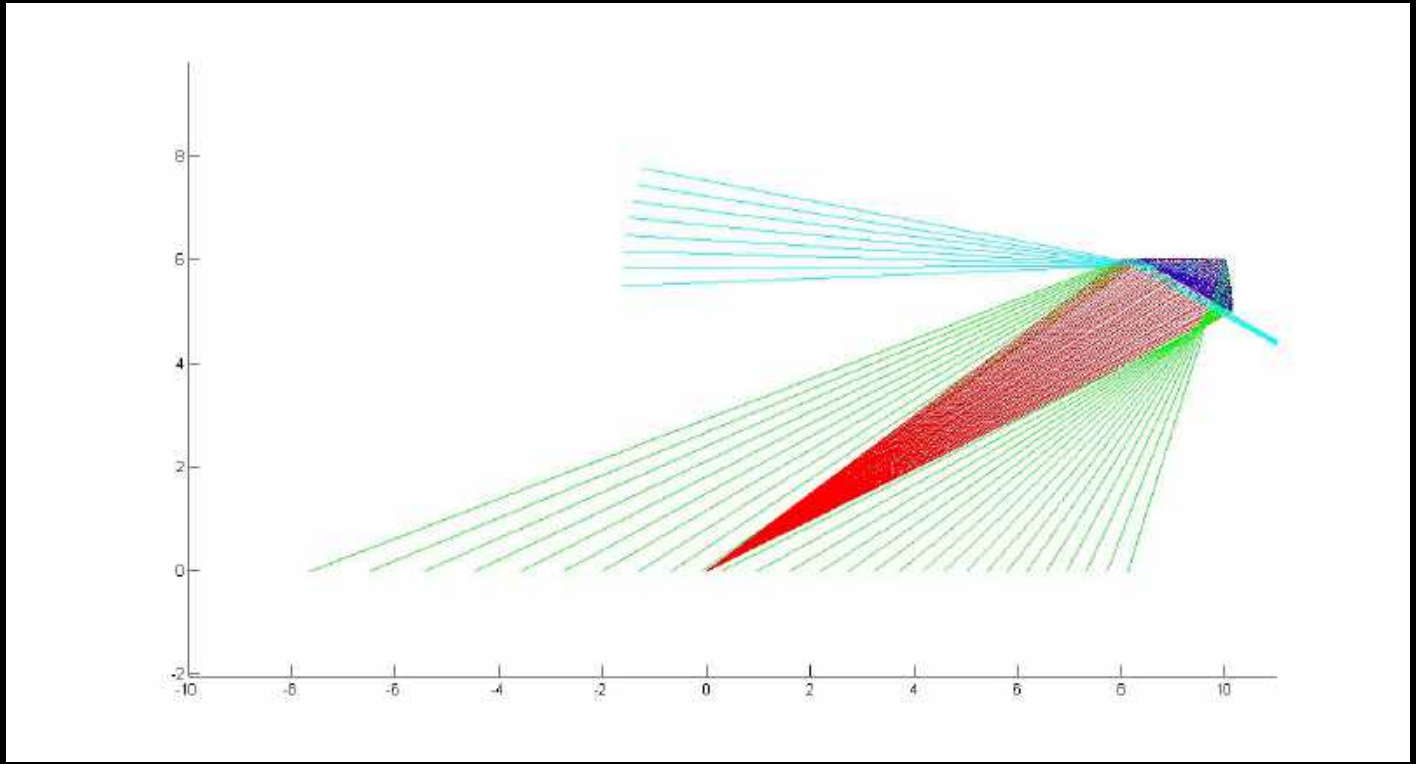
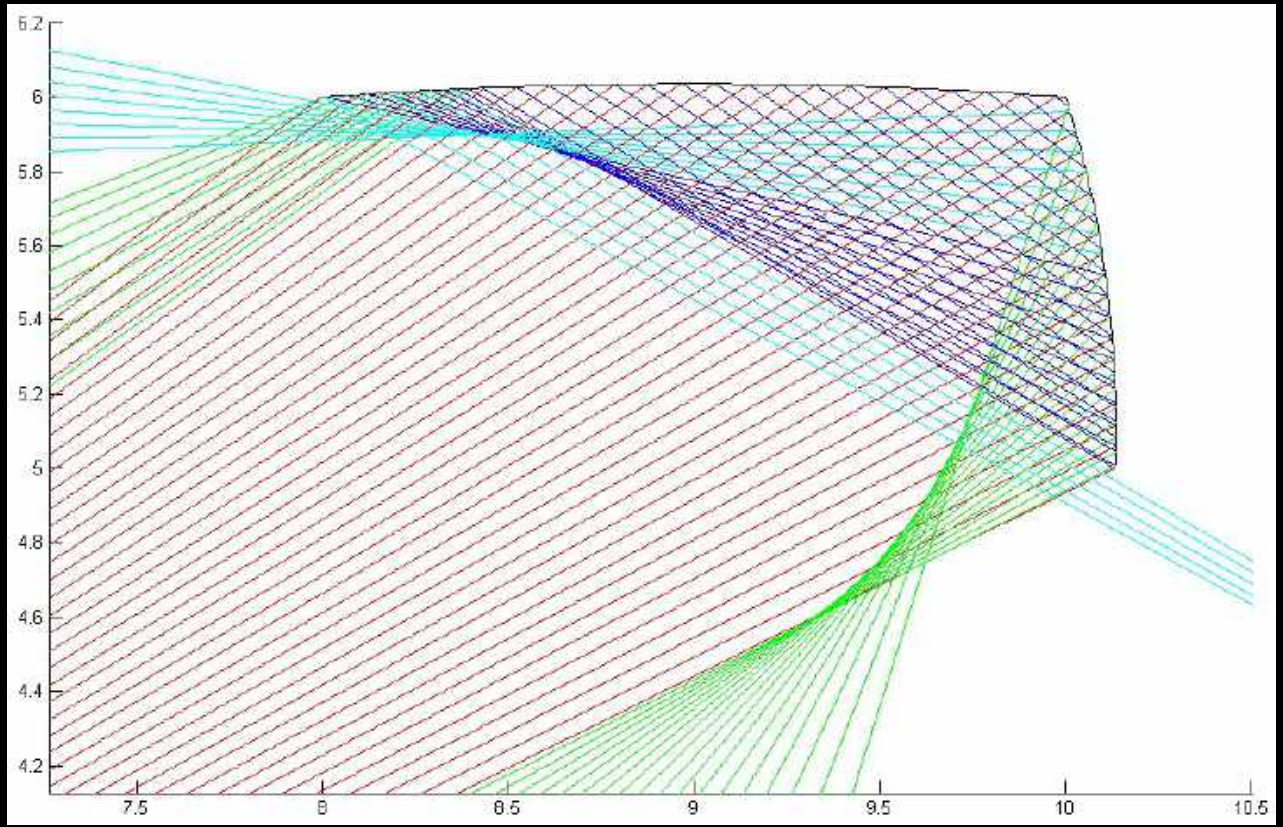


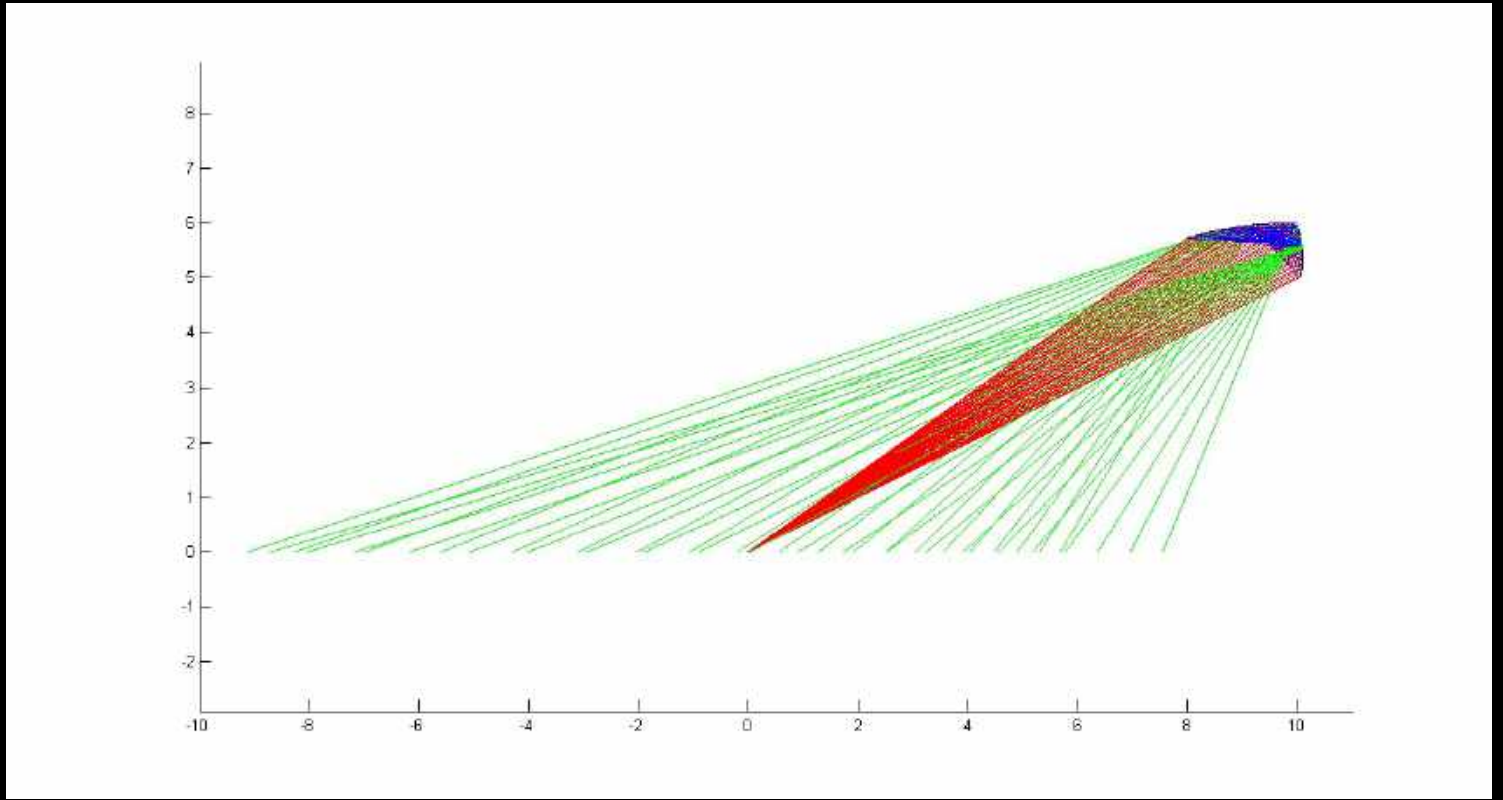
Ideal solution with no overlapping, R1=14m, R2= 3m

2 – Increasing the tool kit – balcony undersides



Close-up of solution with no overlapping

2 – Increasing the tool kit – balcony undersides



Ideal solution with overlapping, R1=7m, R2= 2m

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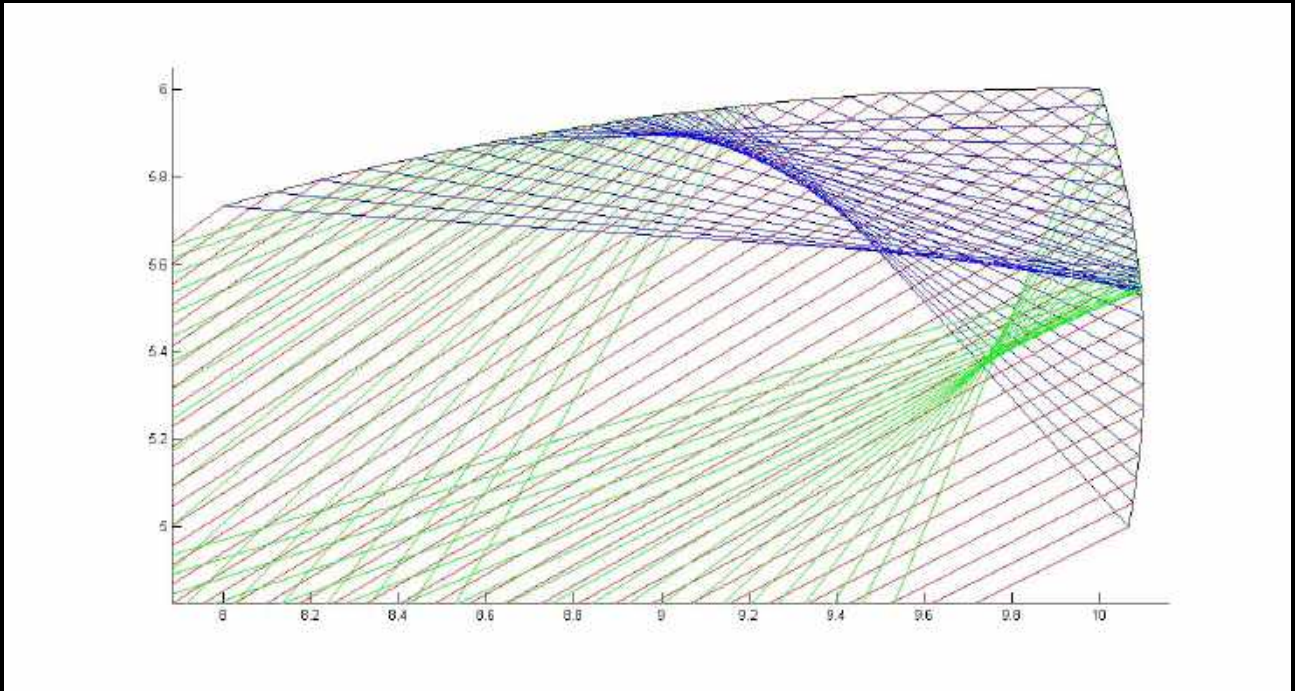


Close-up of ideal solution with overlapping

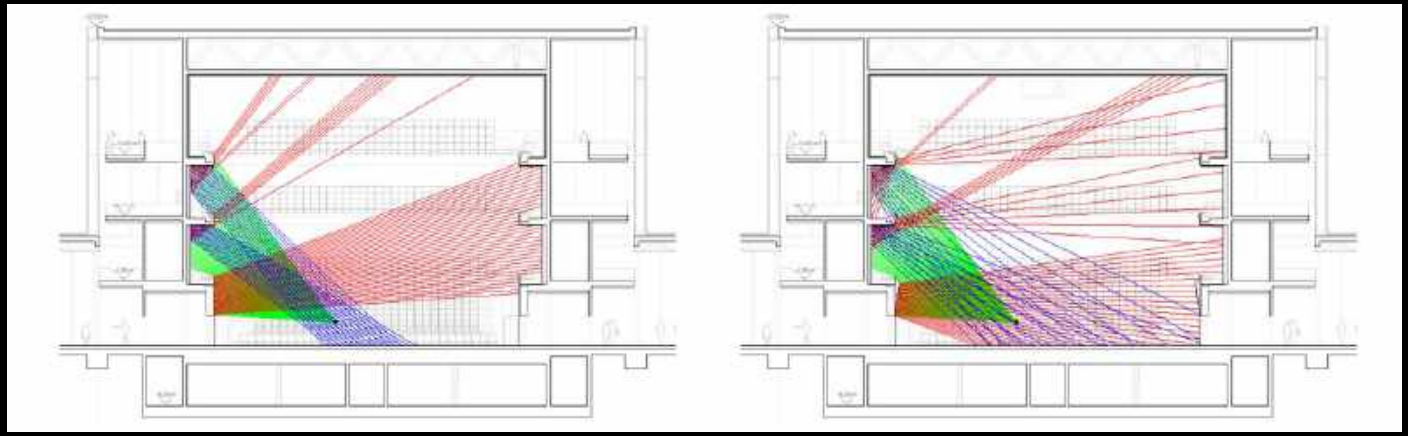
2 – Increasing the tool kit – balcony undersides

They have been built…: Auditorium de Bordeaux, 2013

2 – Increasing the tool kit – balcony undersides

They have been built…: Auditorium de Bordeaux, 2013

2 – Increasing the tool kit – balcony fronts



Competition design
(non-optimized)

- Reflections go up to the ceiling and to side walls
- Reflections in 2nd order only create partial coverage of parterre

With acoustic optimizations
(vertically inclined balcony fronts and convex undersides of balconies)

- Reflection coverage of full parterre and balconies from balcony fronts
- Reflections in 2nd order equally cover the entire parterre

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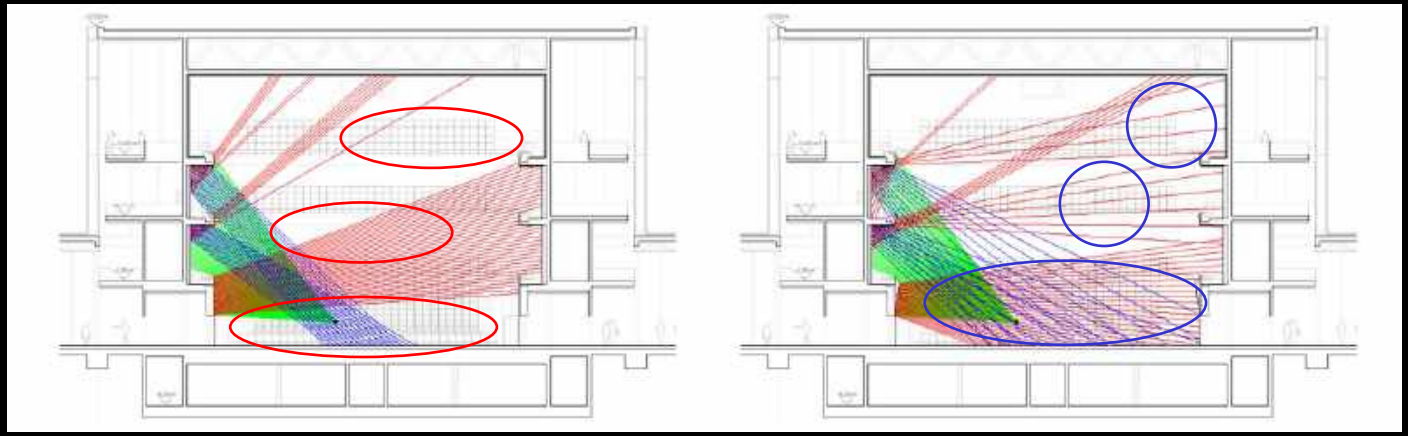
2 – Increasing the tool kit – balcony fronts



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Animation of reflection coverage in short section

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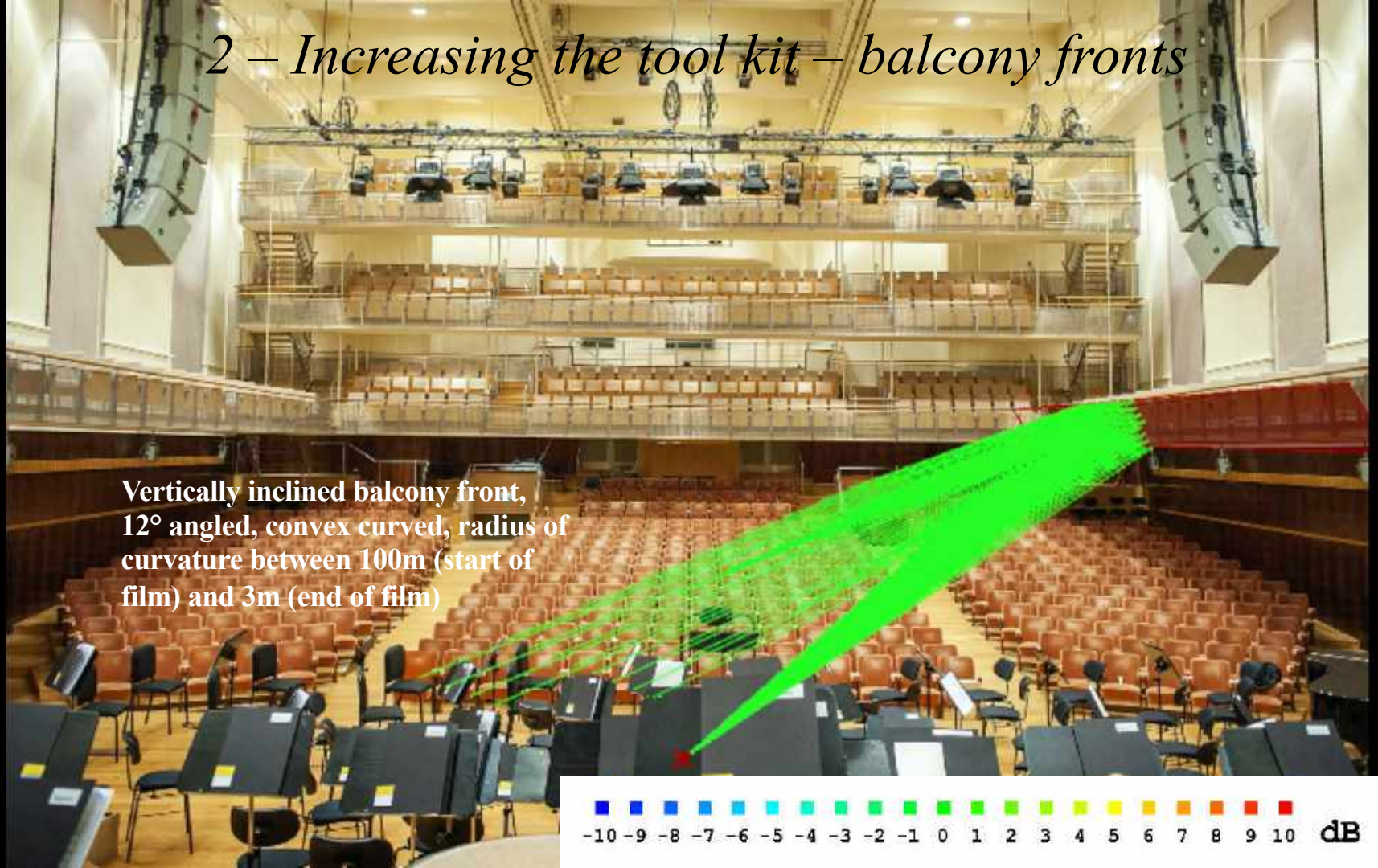
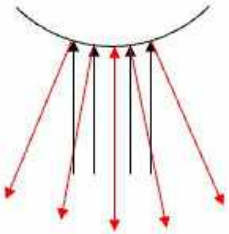
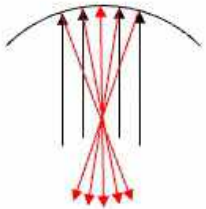


3 – Curved surfaces

Common thinking about curved surfaces



Convex surface
= acoustically diffusing
= GOOD



Concave surface
= acoustically focusing
= BAD

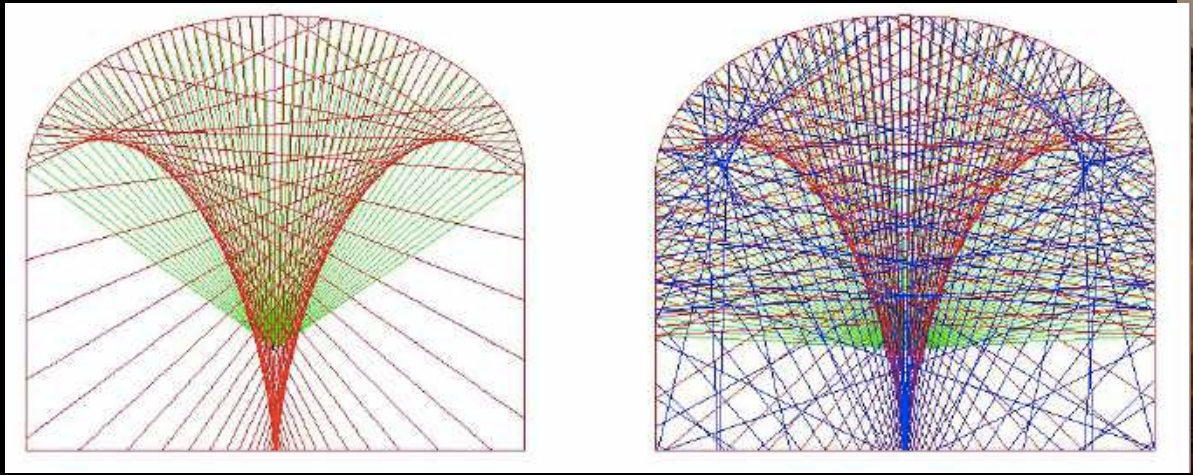
3 – Curved surfaces

La Monnaie / De Munt opera, Brussels

Kulturcasino concert hall, Bern

So why do these historic halls work well?

3 – Curved surfaces

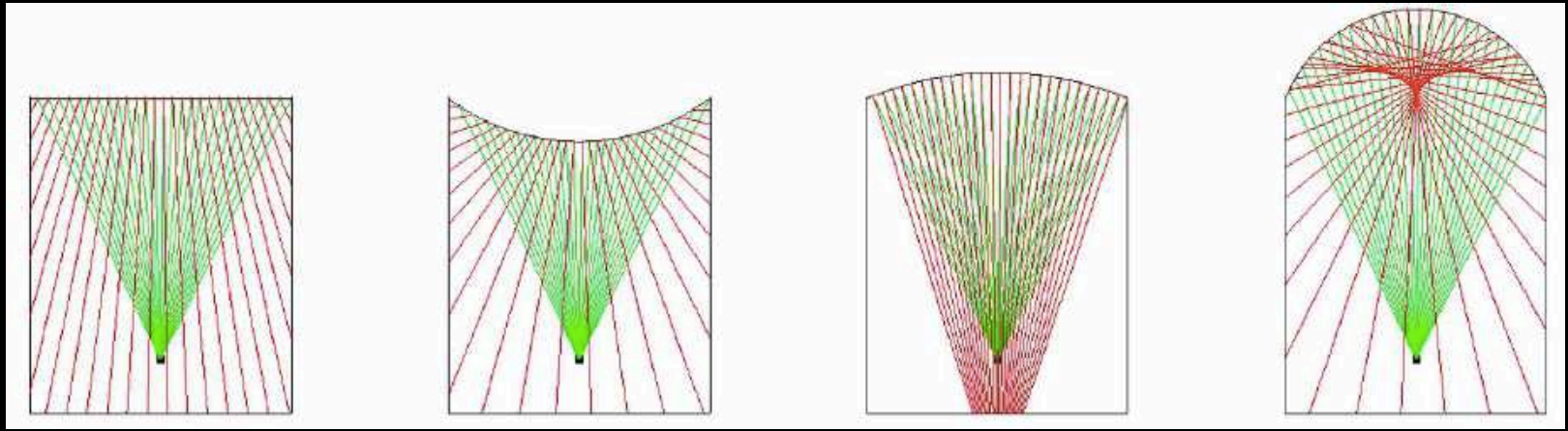


1st order reflections

2nd order reflections

Wigmore Hall, London, 550 seats, 1901

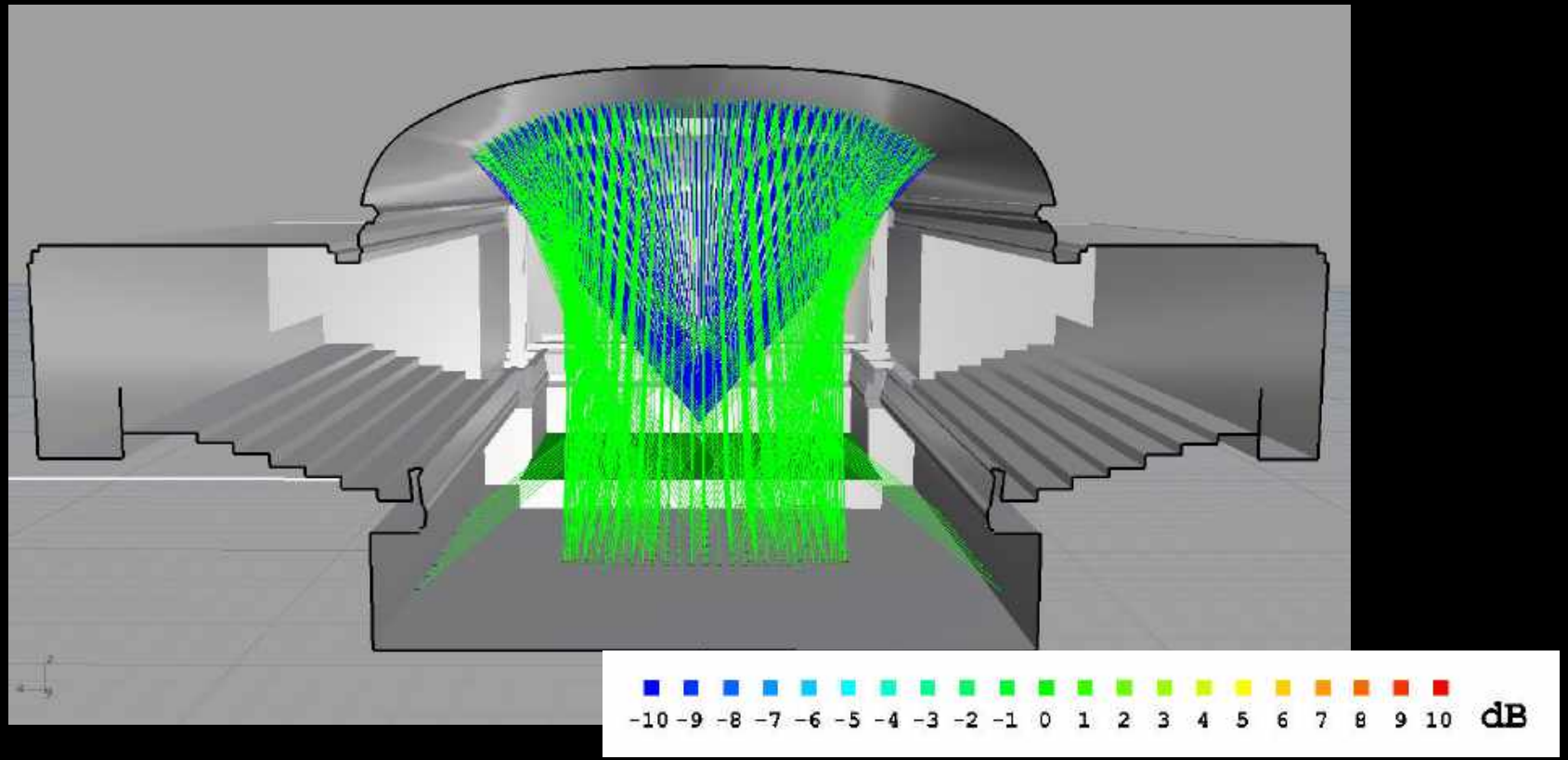
3 – Curved surfaces



1	2	3	4
flat surface → REFERENCE	convex → diffusion	concave → focusing	concave → diffusion

If focusing can be kept outside audience plane and/or kept moderate, then *all* curved surfaces can be beneficial

3 – Curved surfaces

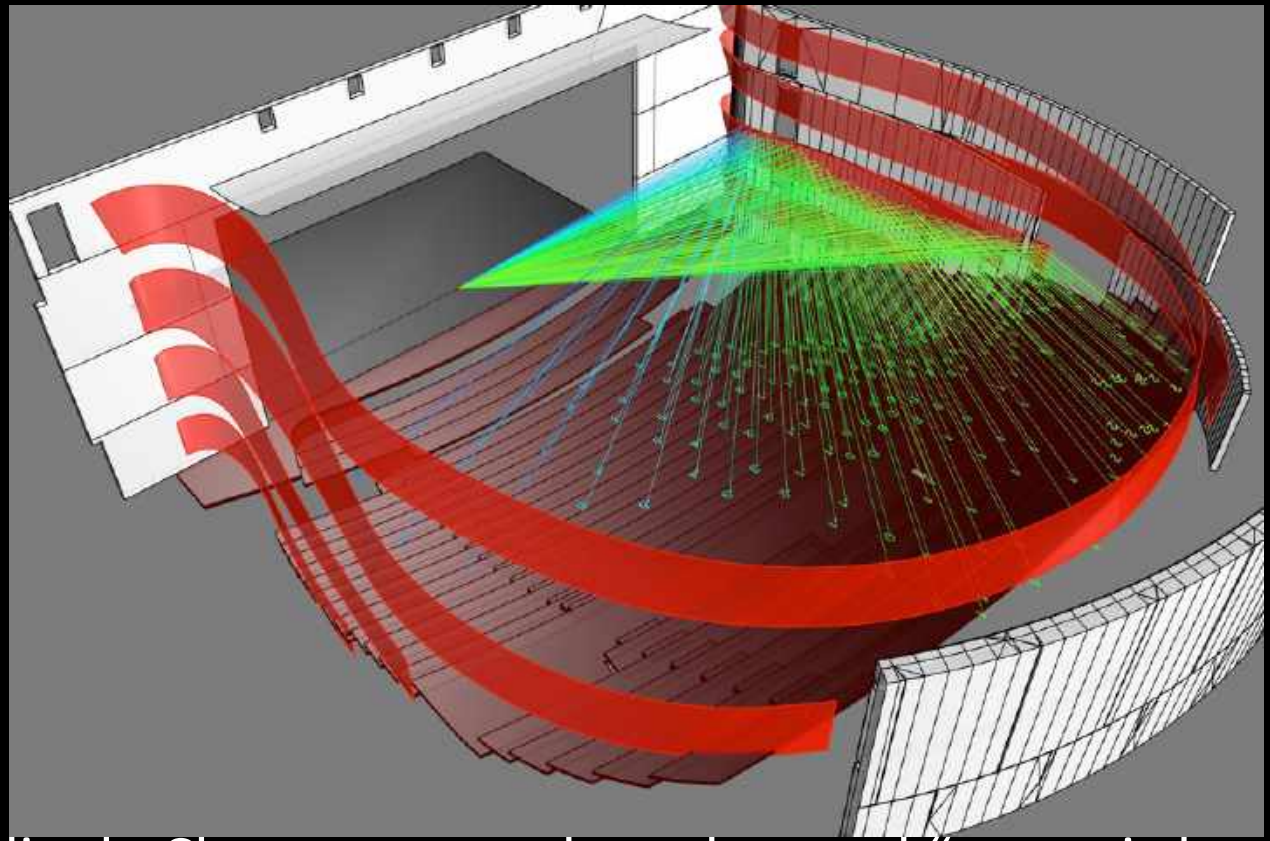


Kulturcasino Bern: moderate focusing and some spreading…

3 – Curved surfaces

Comédie de Clermont: cupola and curved “acoustic bands”…

3 – Curved surfaces



Comédie de Clermont: cupola and curved “acoustic bands”…

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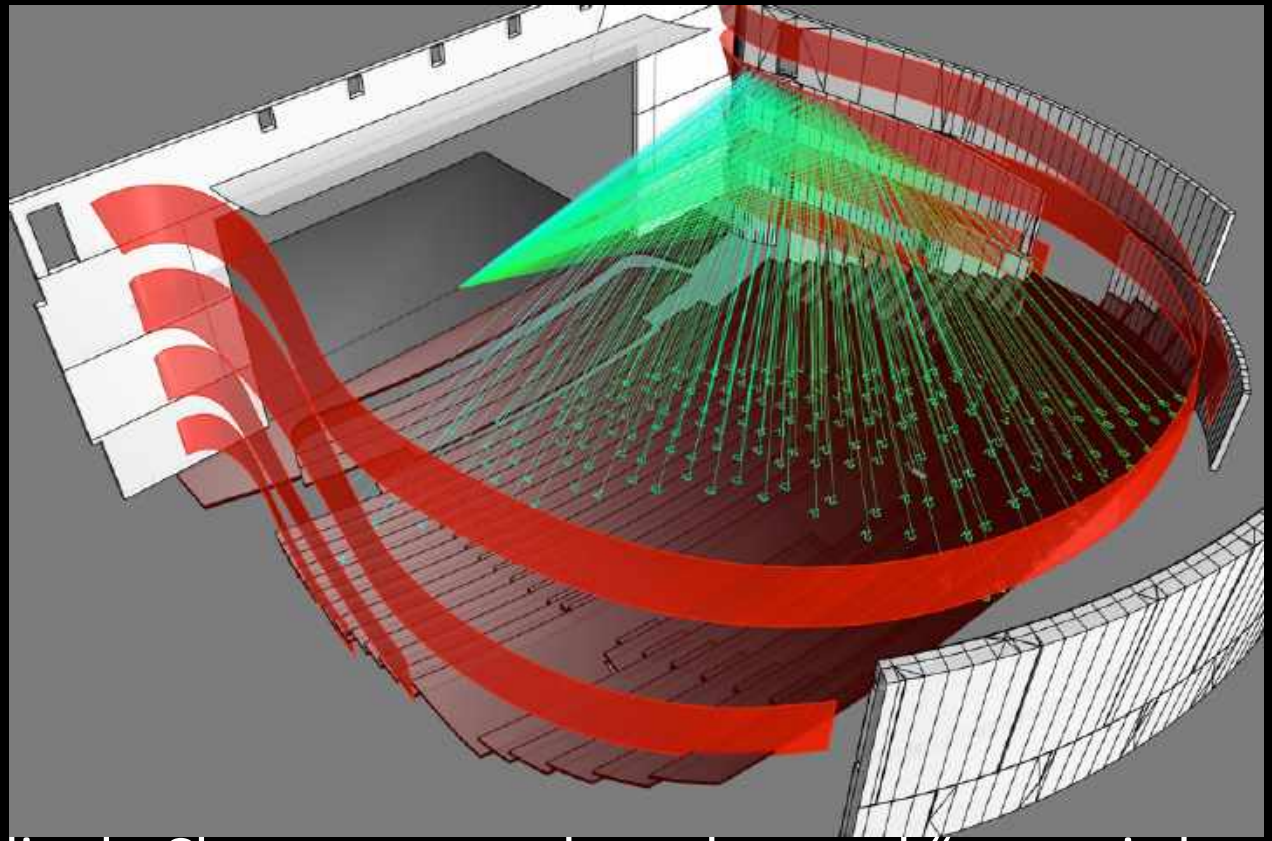
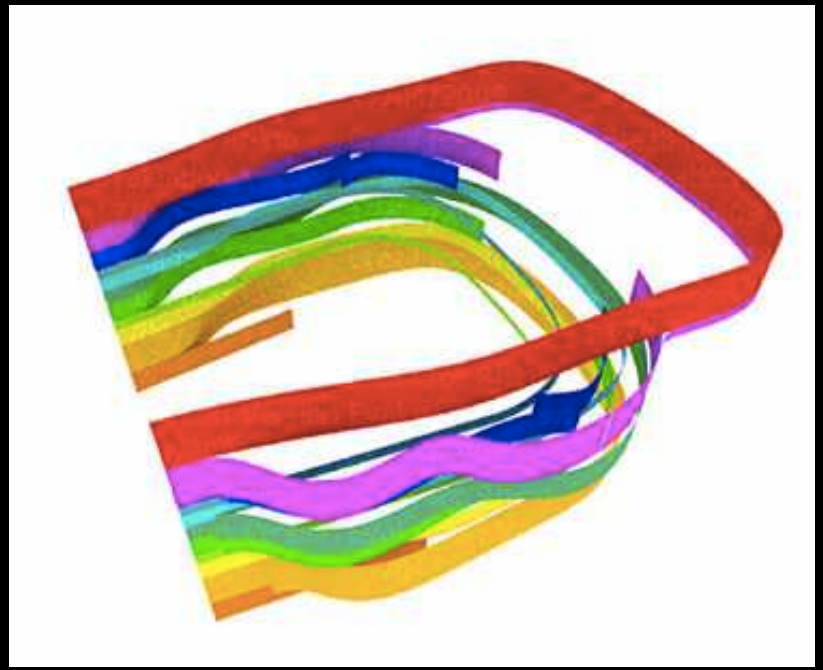


Comédie de Clermont: cupola and curved “acoustic bands”…

4 – Every architectural design is different

Wuxi Grand Theatre - “banded” opera house



Architect: Martin Lukasczyk (PESark)

4 – Every architectural design is different

Wuxi Grand Theatre - “banded” opera house

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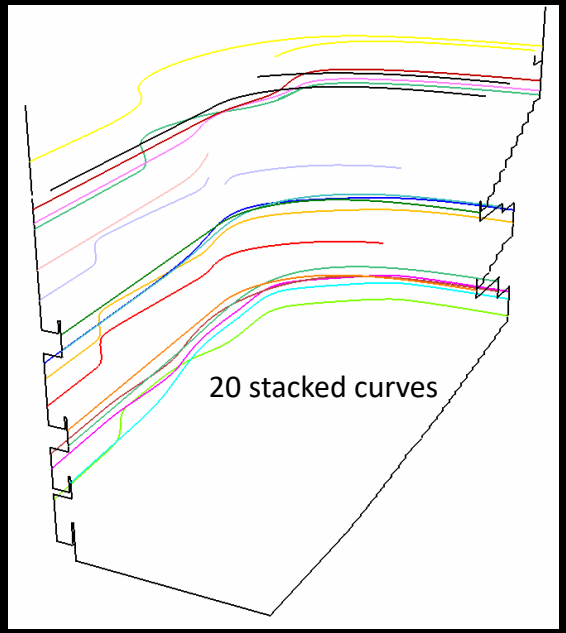
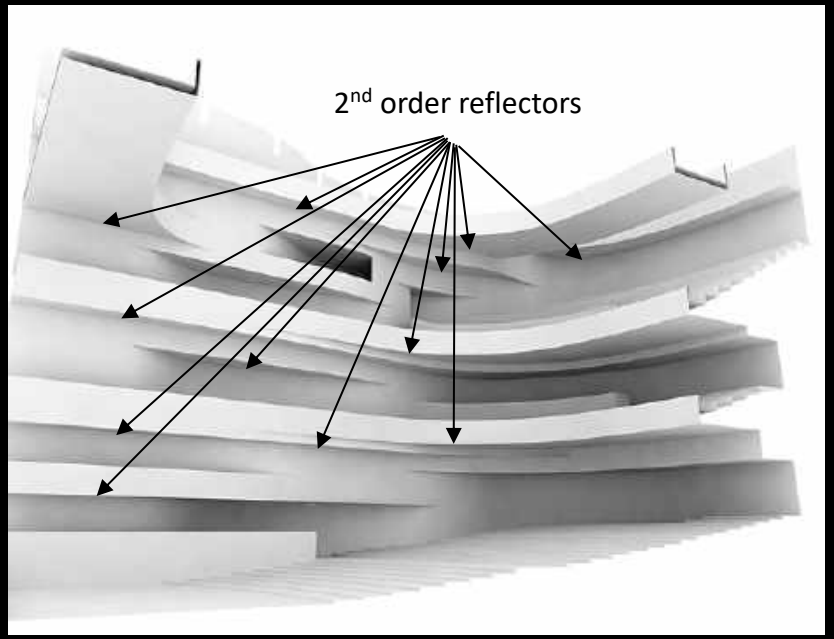
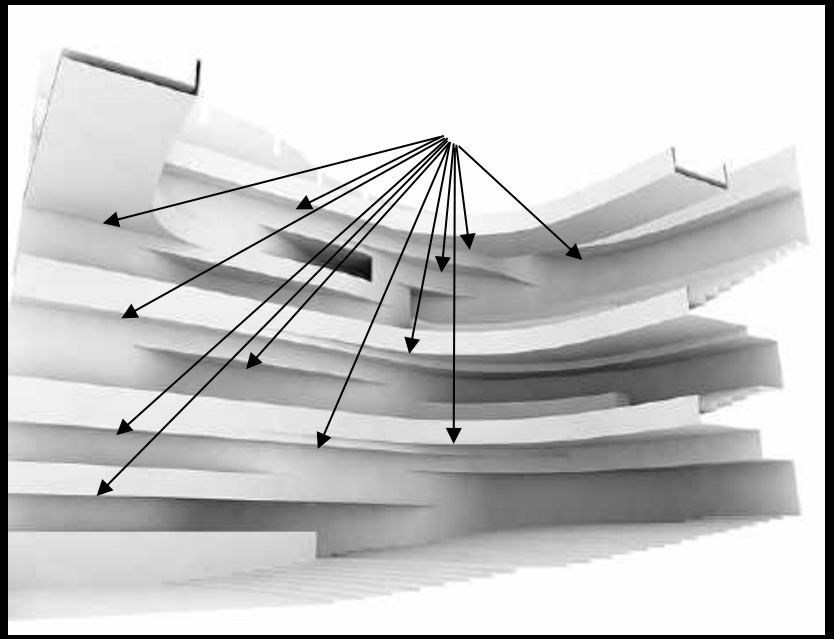
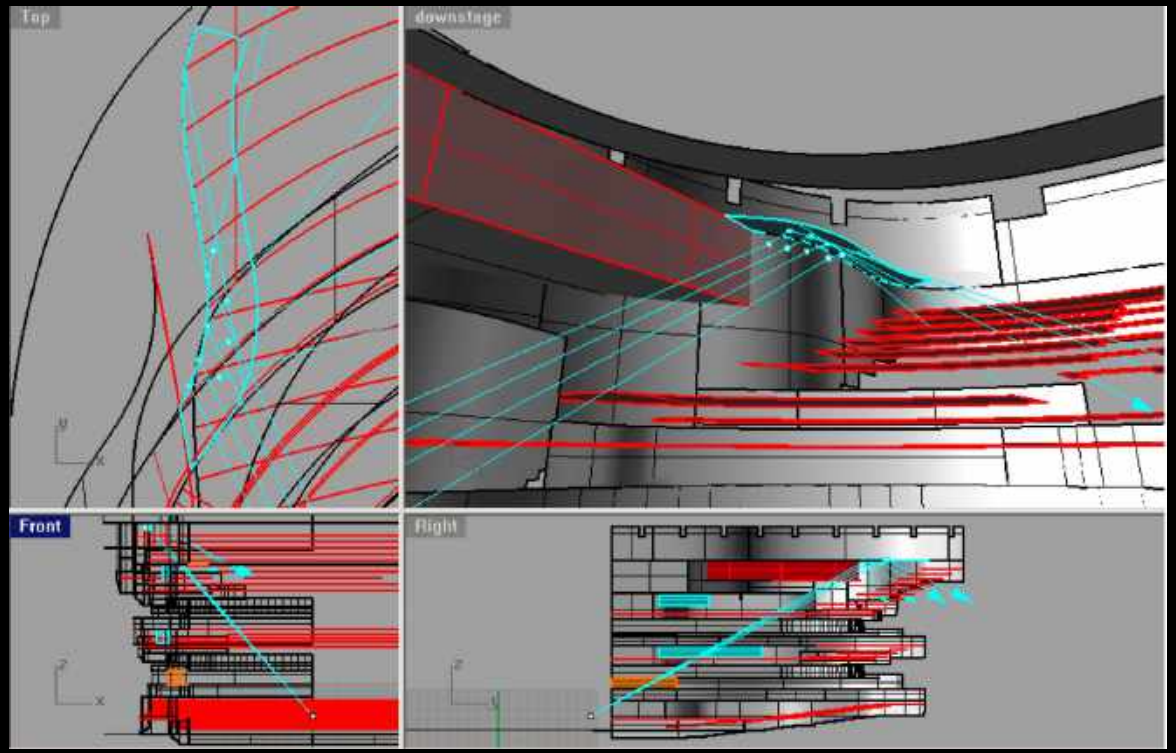




Wuxi Grand Theatre - “banded” opera house



Rhino (3D NURBS modeling)



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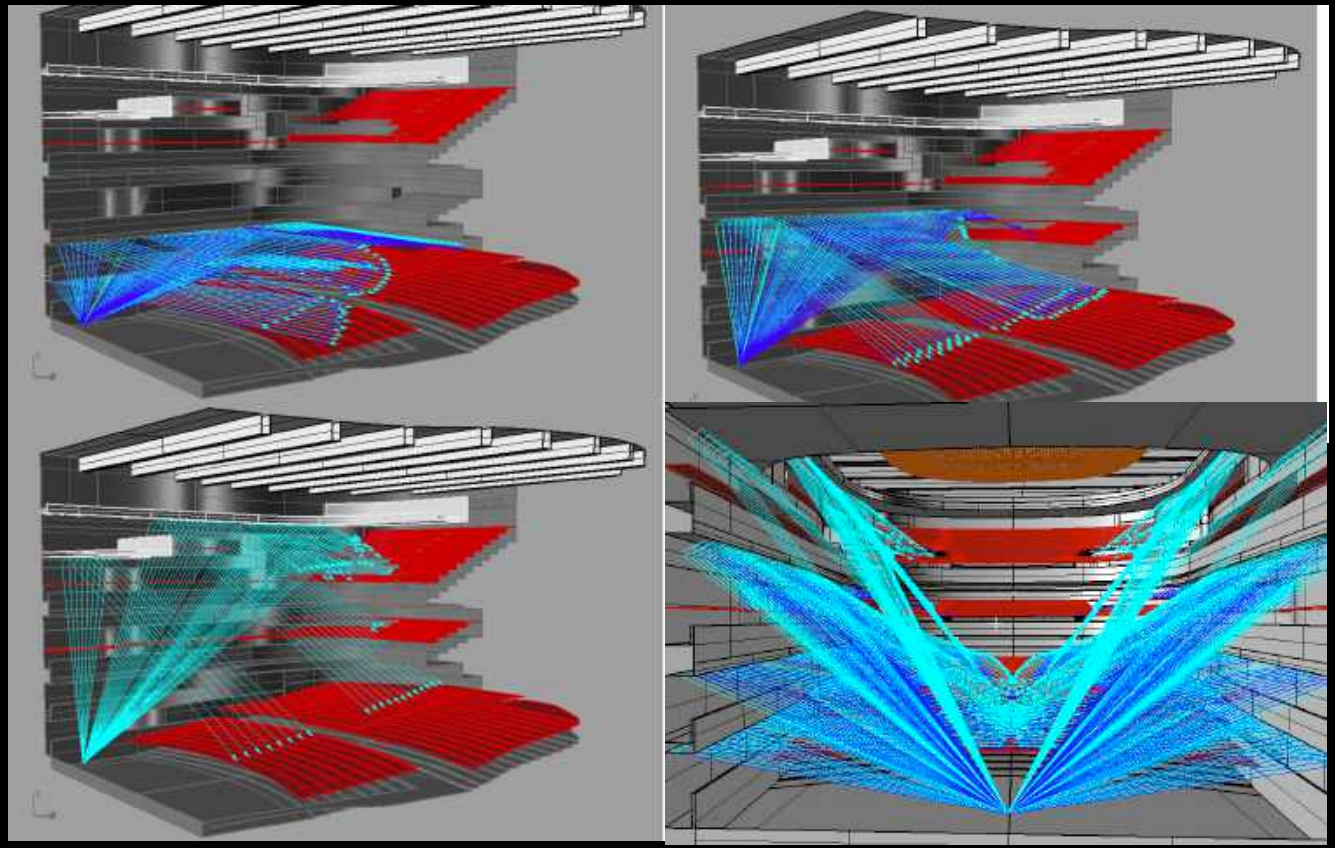


We may be approaching our 15 reflections here…!

4 – Because every architectural design is different

Opéra des Nations, Geneva, 1100 seats

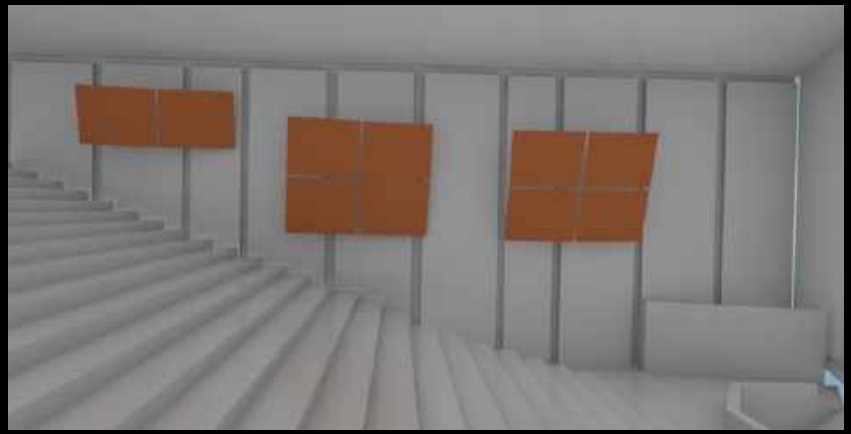
4 – Because every architectural design is different

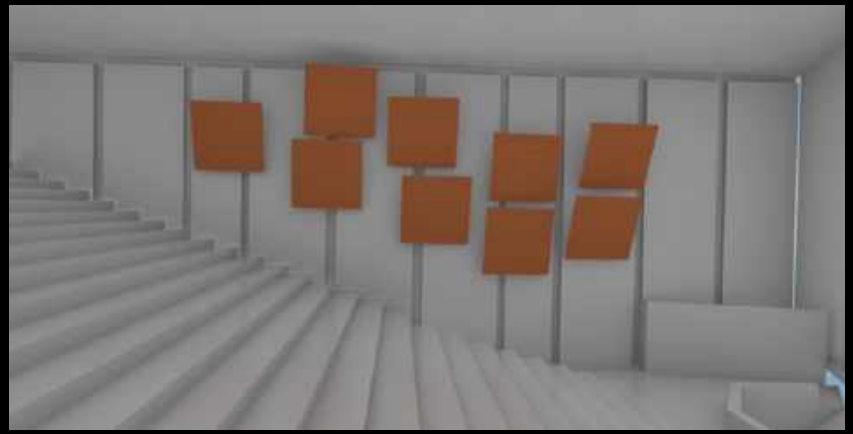
Théâtre Ephémère de la Comédie Française, 700 seats

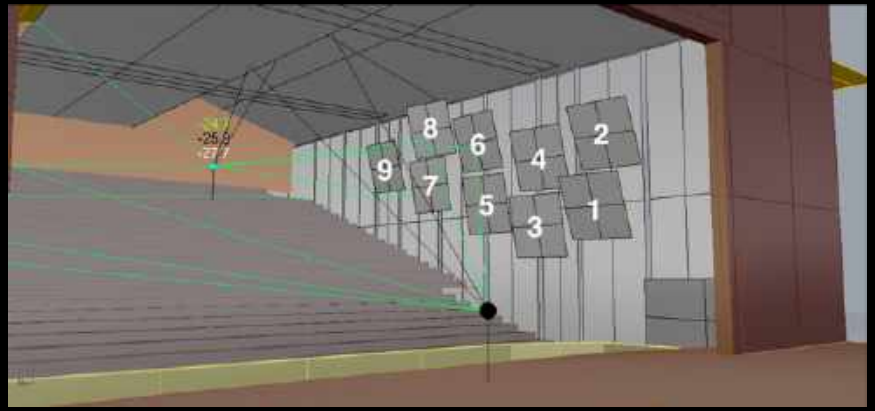
4 – Because every architectural design is different

Ceiling reflectors not required/beneficial for opera!?!

4 – Because every architectural design is different

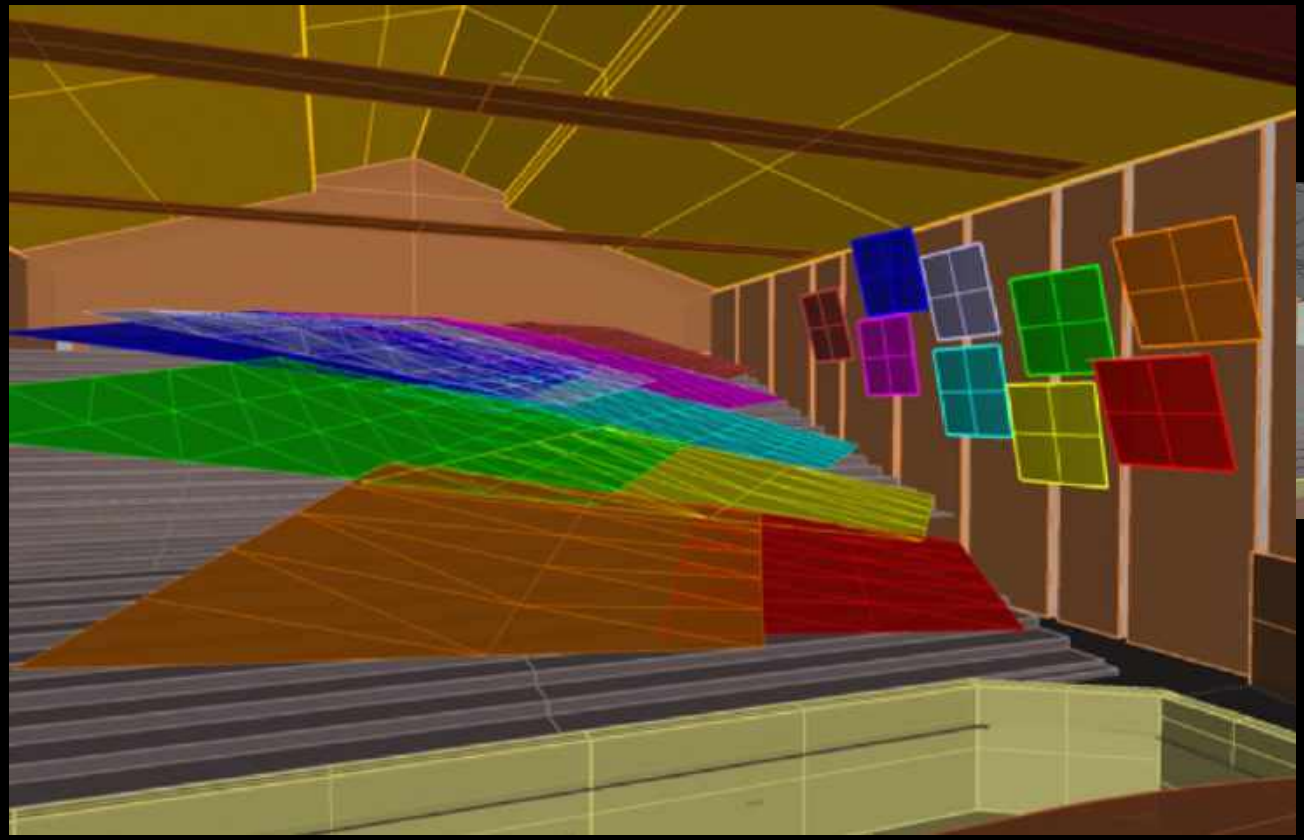


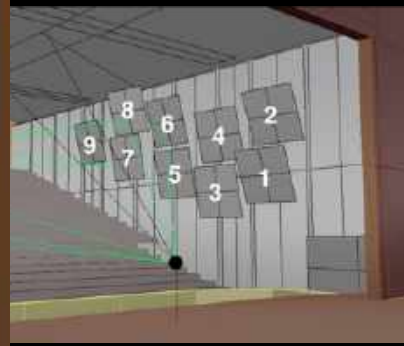




Opéra des Nations, Geneva, 1100 seats

4 – Because every architectural design is different

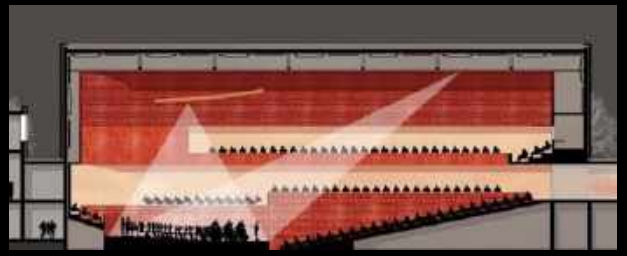


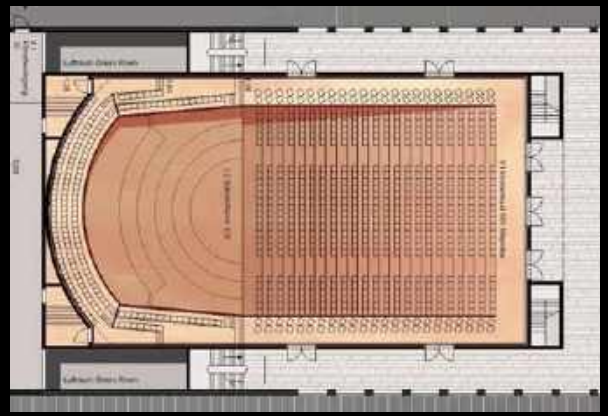


Opéra des Nations, Geneva, 1100 seats – full coverage through side reflectors

5 – Getting away from the "shoebox or vineyard"

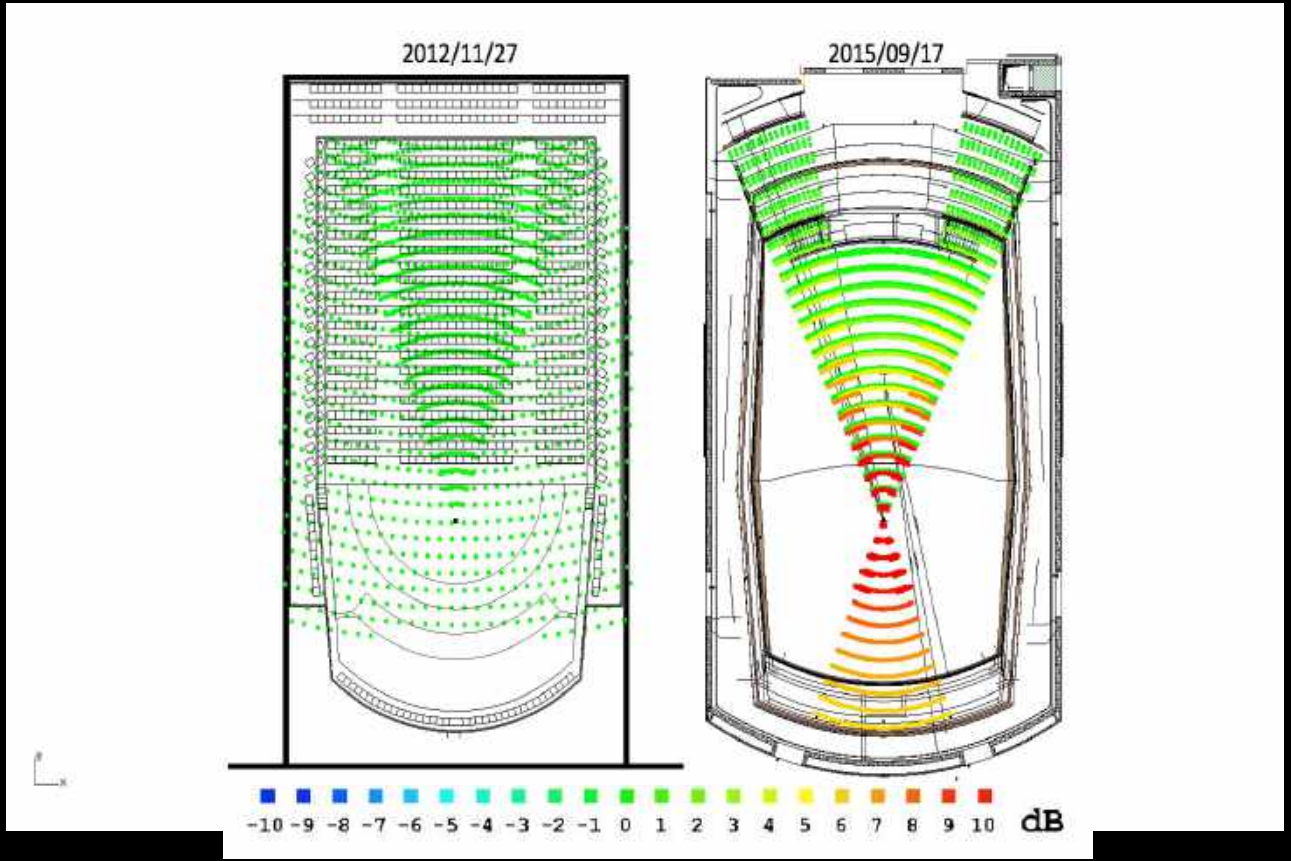
5 – Getting away from the "shoebox or vineyard"



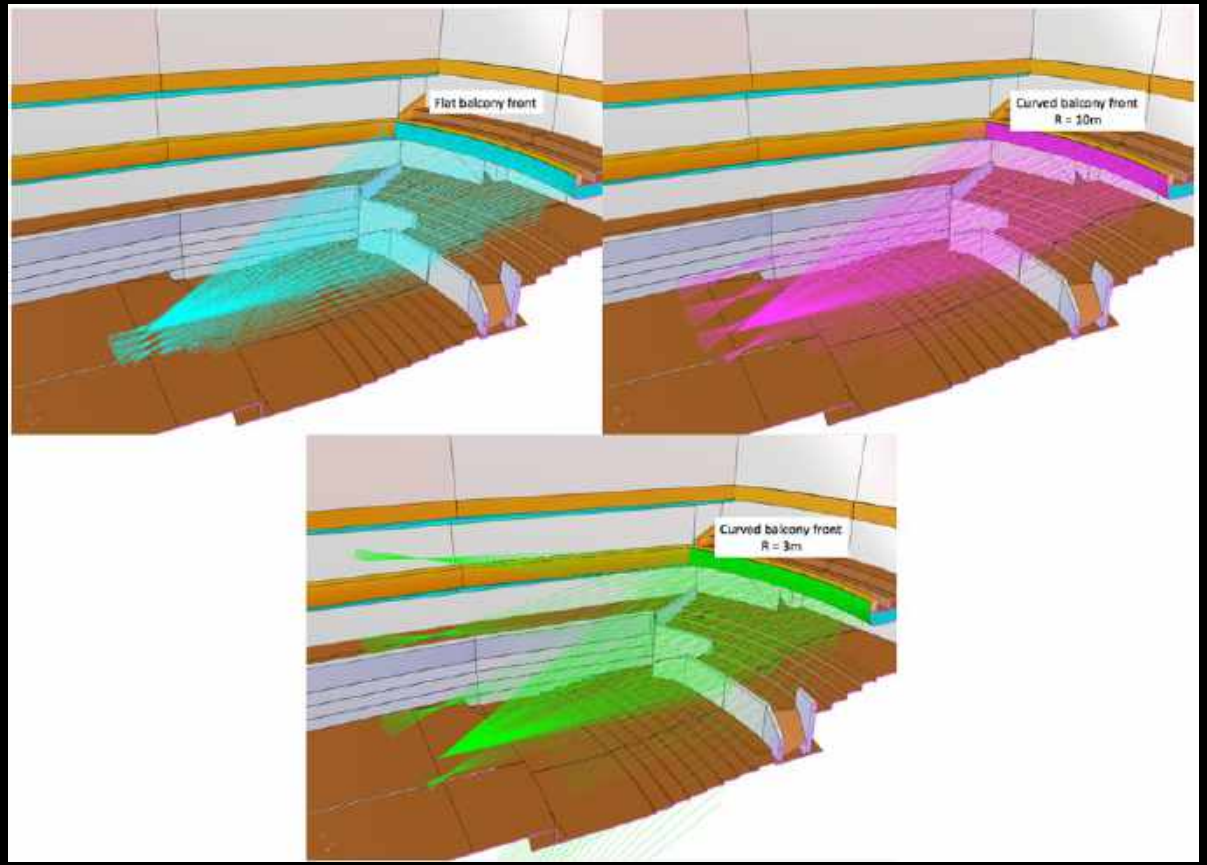


Musikforum Bochum, competition design

5 – Getting away from the "shoebox or vineyard"



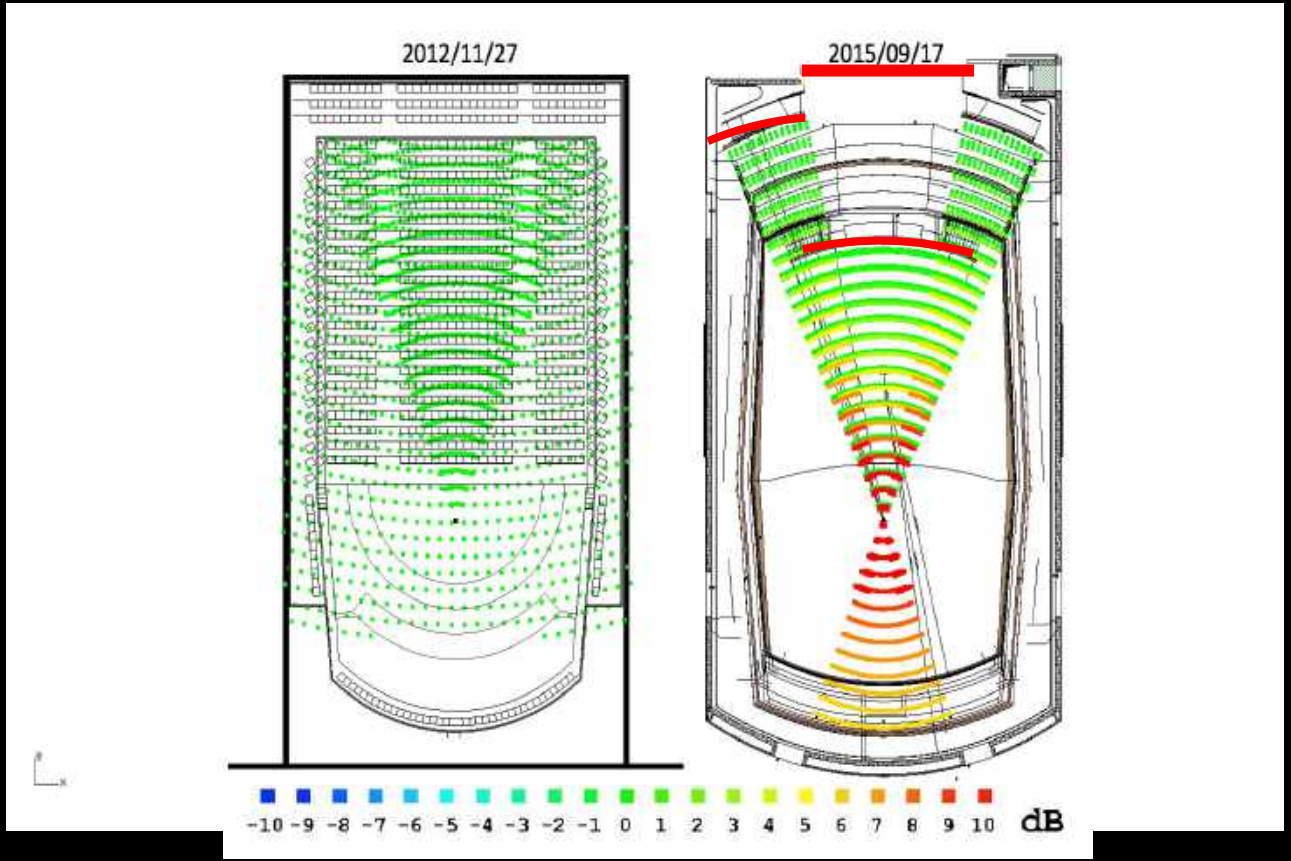
5 – Getting away from the "shoebox or vineyard"



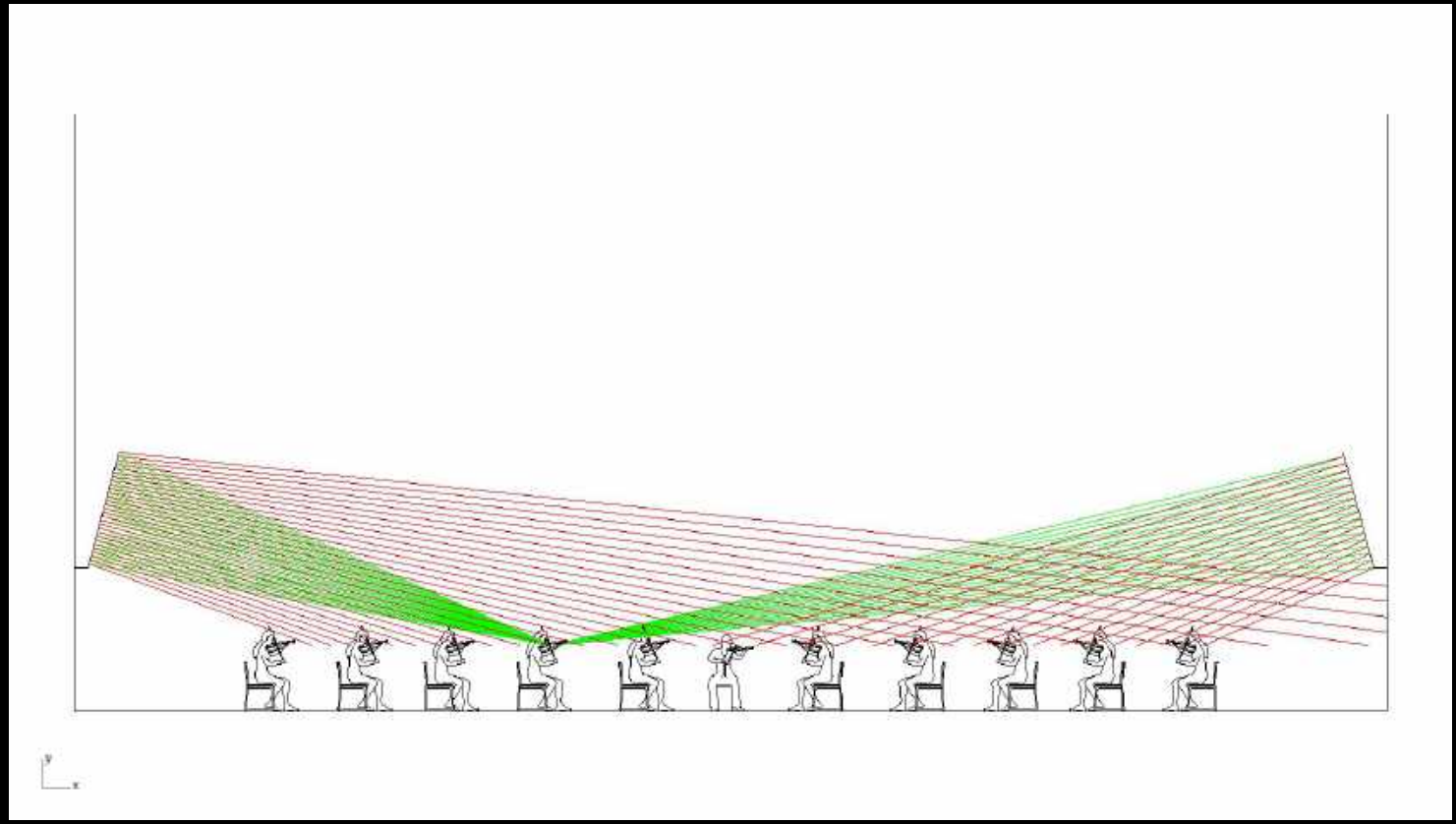
Rather than fighting the architectural concept, the focusing on stage was solved in 3D by breaking up in plan some of the curves into a number of segments, by optimising the radius of curvature of each segment, and by angling the segments in section in order to send the focal points safely above the heads of the musicians.

All optimisations were carried out by means of parametric modelling in Rhino/Grasshopper with real-time monitoring of the focusing behaviour and amplitude up to 3rd reflection order. Some balcony fronts were also given a convex shape in section in order to distribute the sound energy to alleviate focussing hot spots and eliminate flutter echoes.

5 – Getting away from the "shoebox or vineyard"



5 – Getting away from the "shoebox or vineyard"

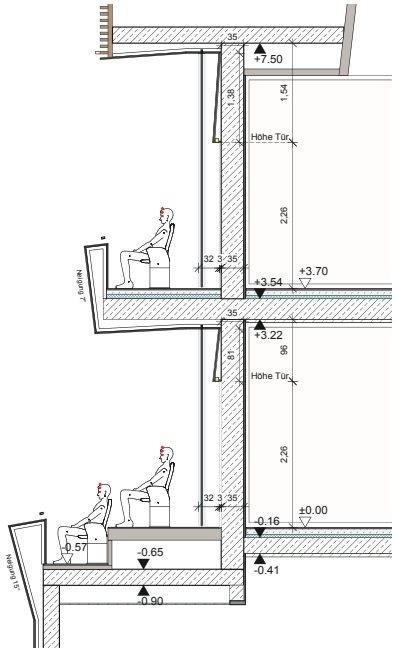


Vertically inclined balcony fronts as cross-communication reflectors for musicians

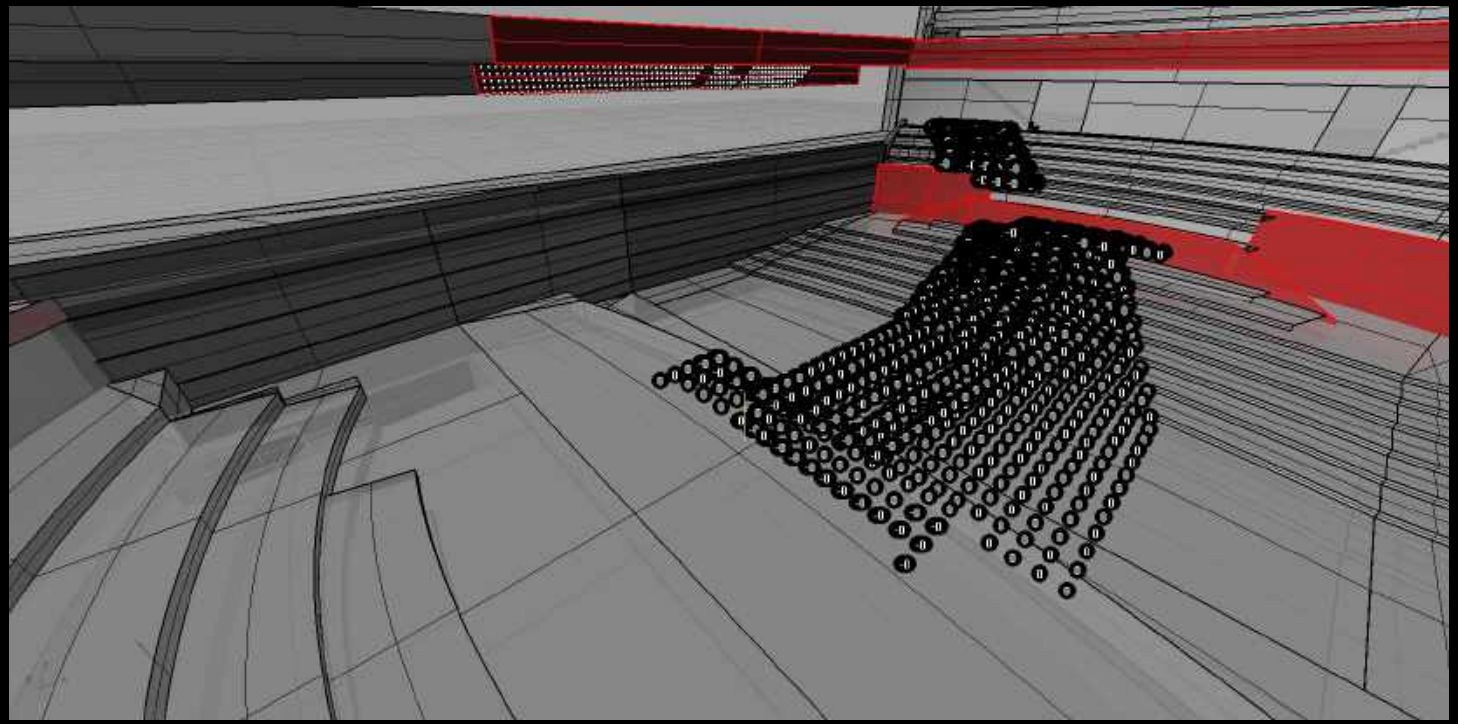
5 – Getting away from the “shoebox or vineyard”

VARIANTE SAALWAND - Neigung nach hinten, Vorhang bis ganz oben

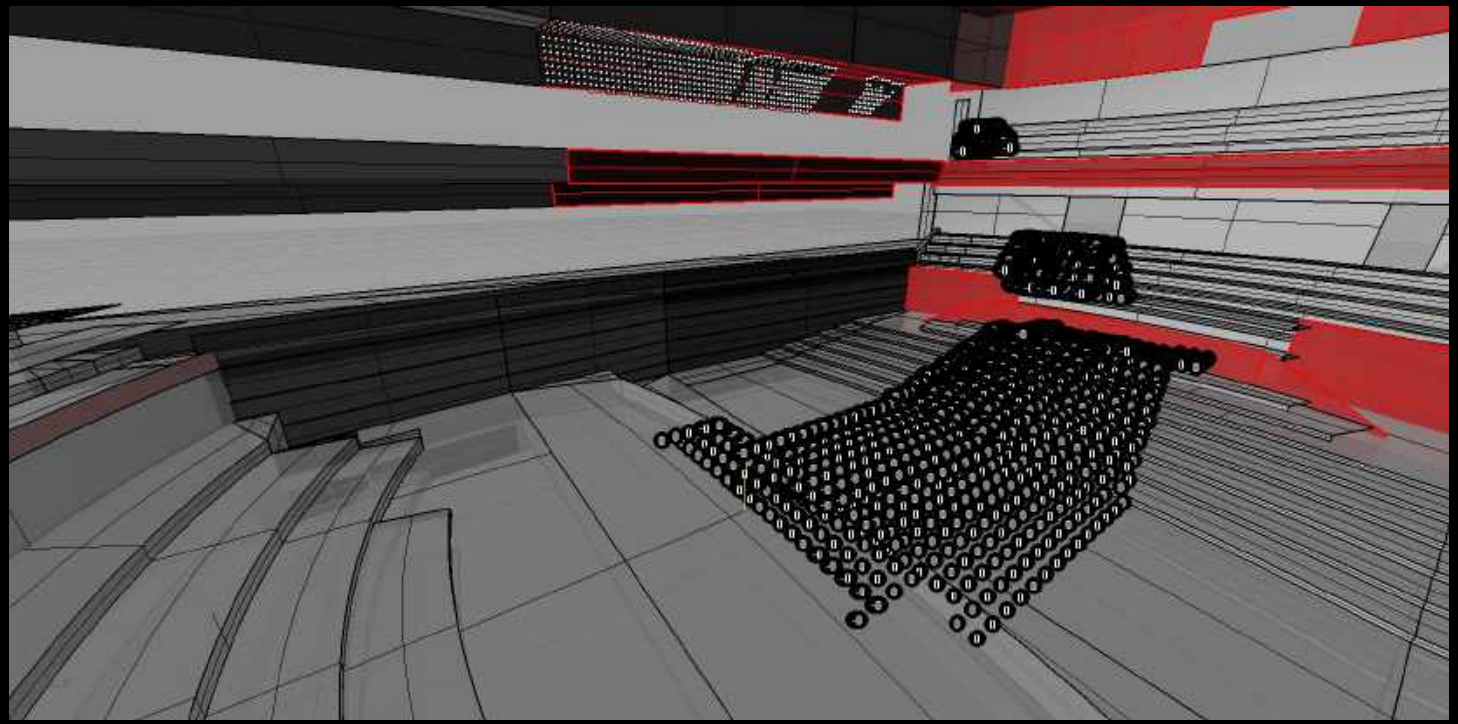
Unterer Wandbereich: bis obere Türkante (2,26 m), keine Neigung
Oberer Wandbereich: nach hinten geneigt; Neigung variabel
Fläche Balkonuntersicht: Neigung im EG und 1. OG variabel



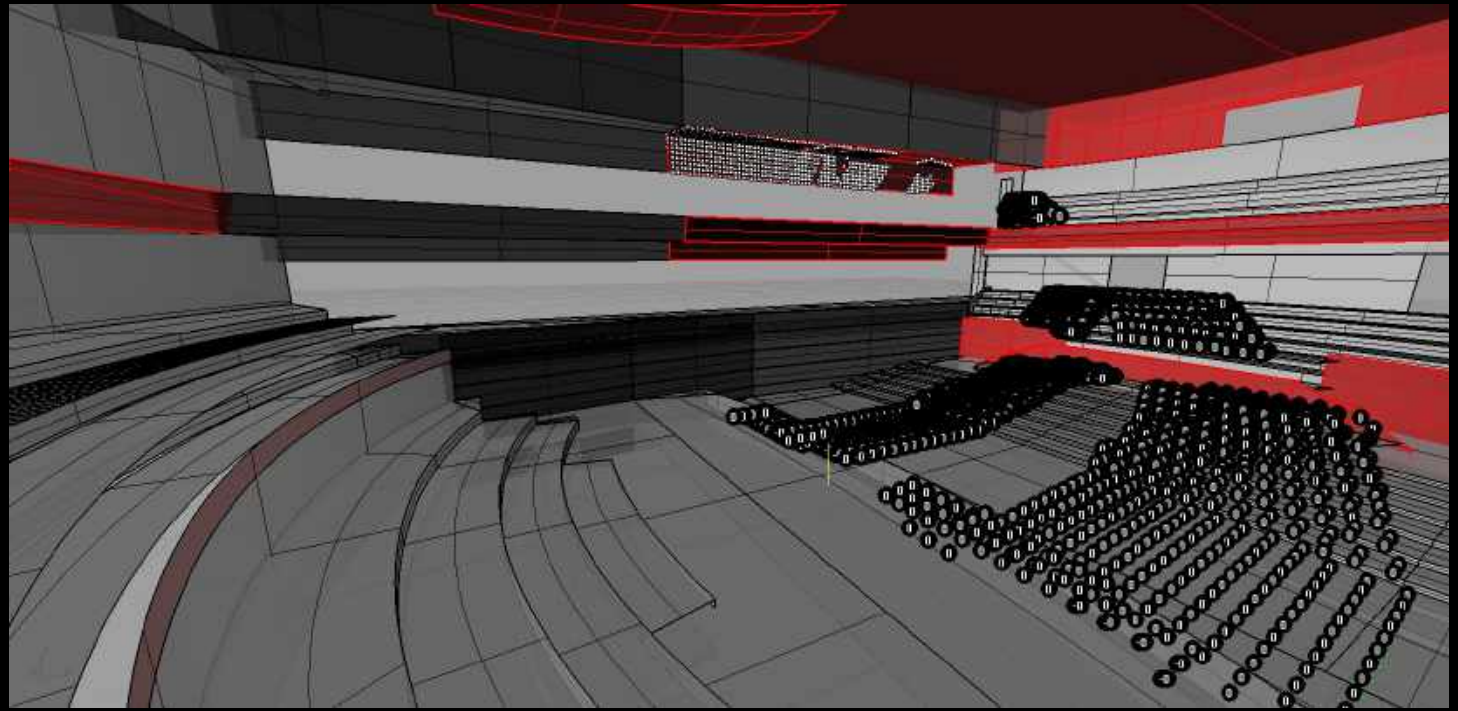
Lower soffit
S1 – 2° to 3°
Downstand vertical



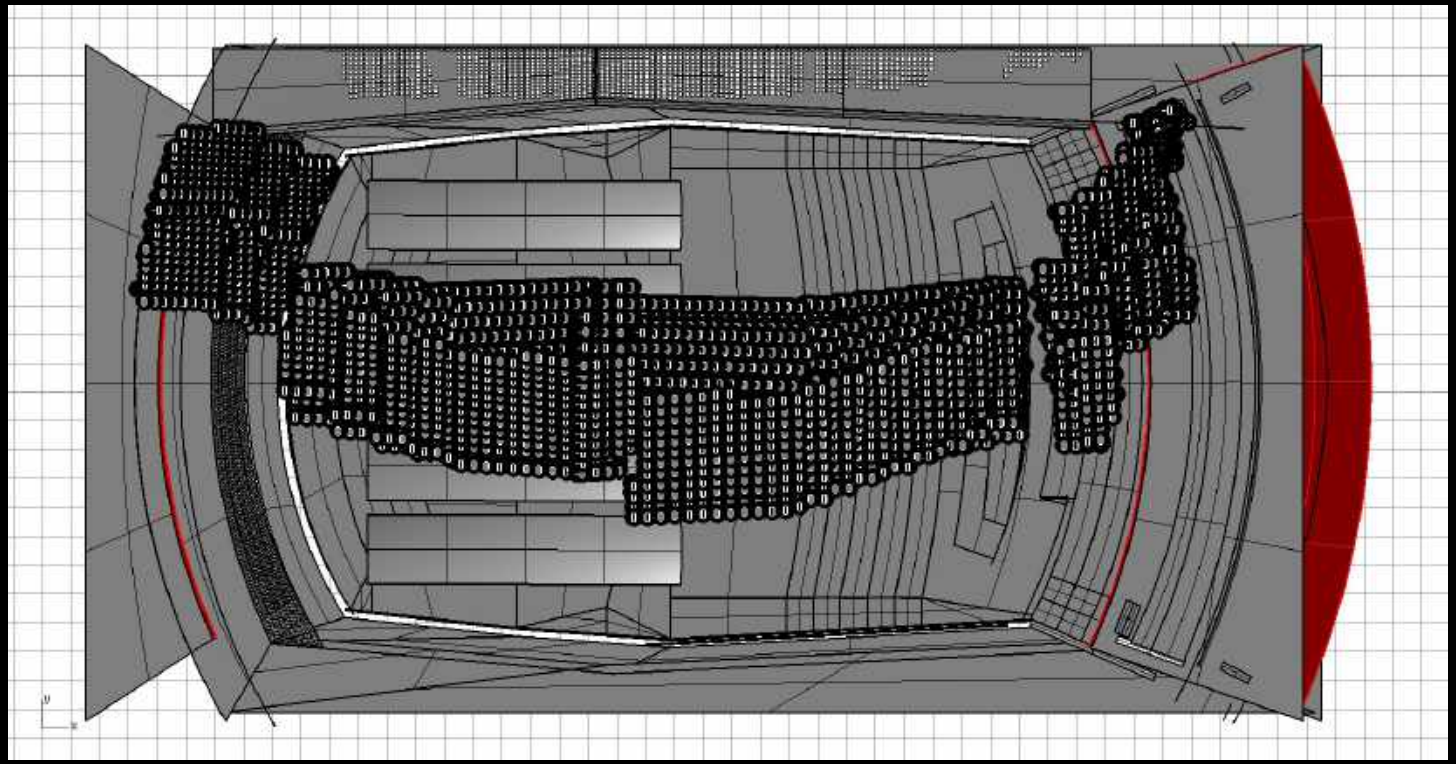
Upper soffit
S1 – h 3° to 4° - v 0°



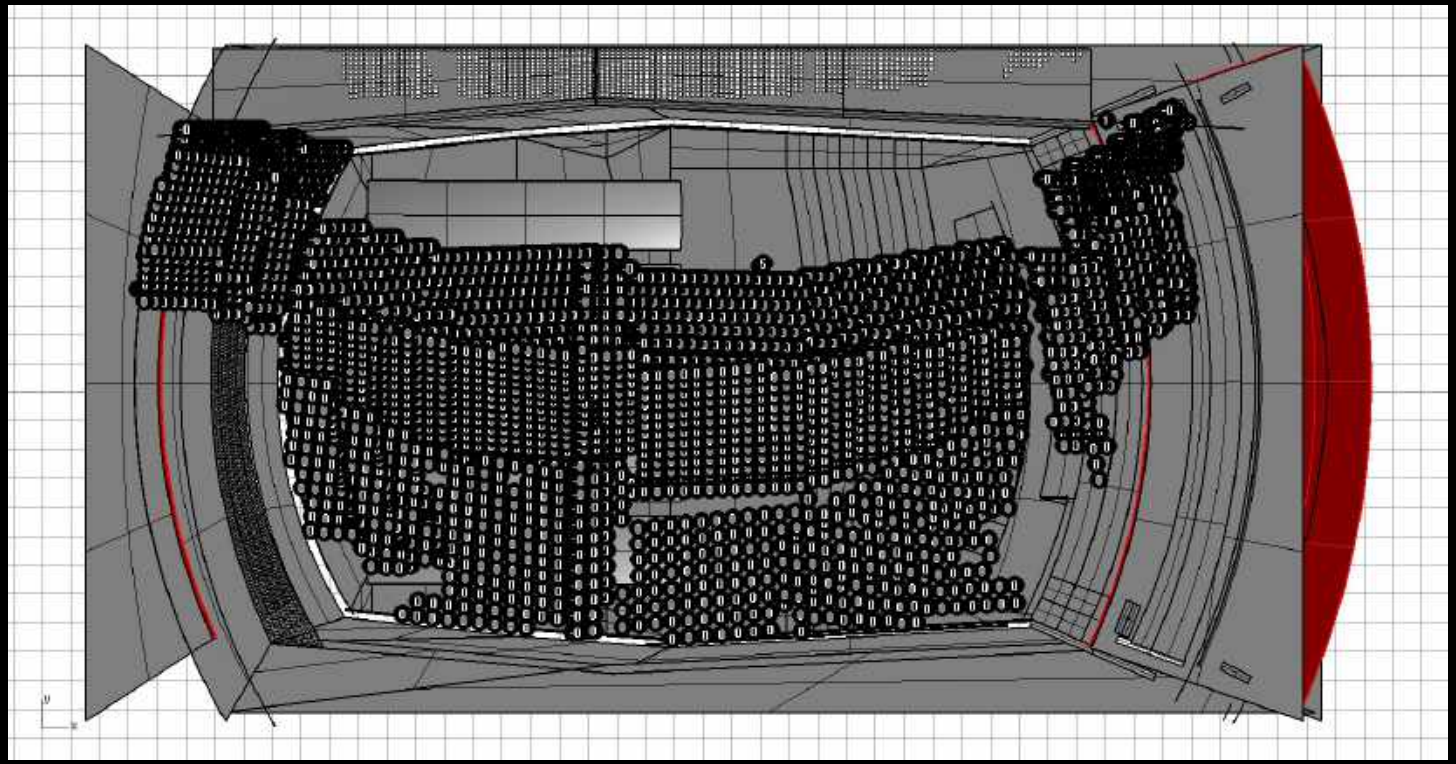
Upper soffit
S1 – h 3° to 4° - v 3°



Lower soffit (h 2° to 3° v 0°) + upper soffit (h 3° to 4° - v 0°)
S1

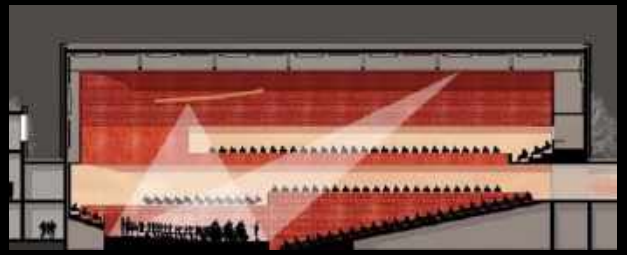


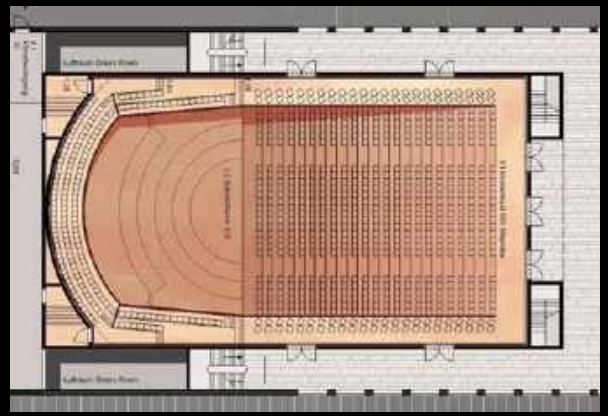
Lower soffit (h 2° to 3° v 3°) + upper soffit (h 3° to 4° - v 0°)
S1

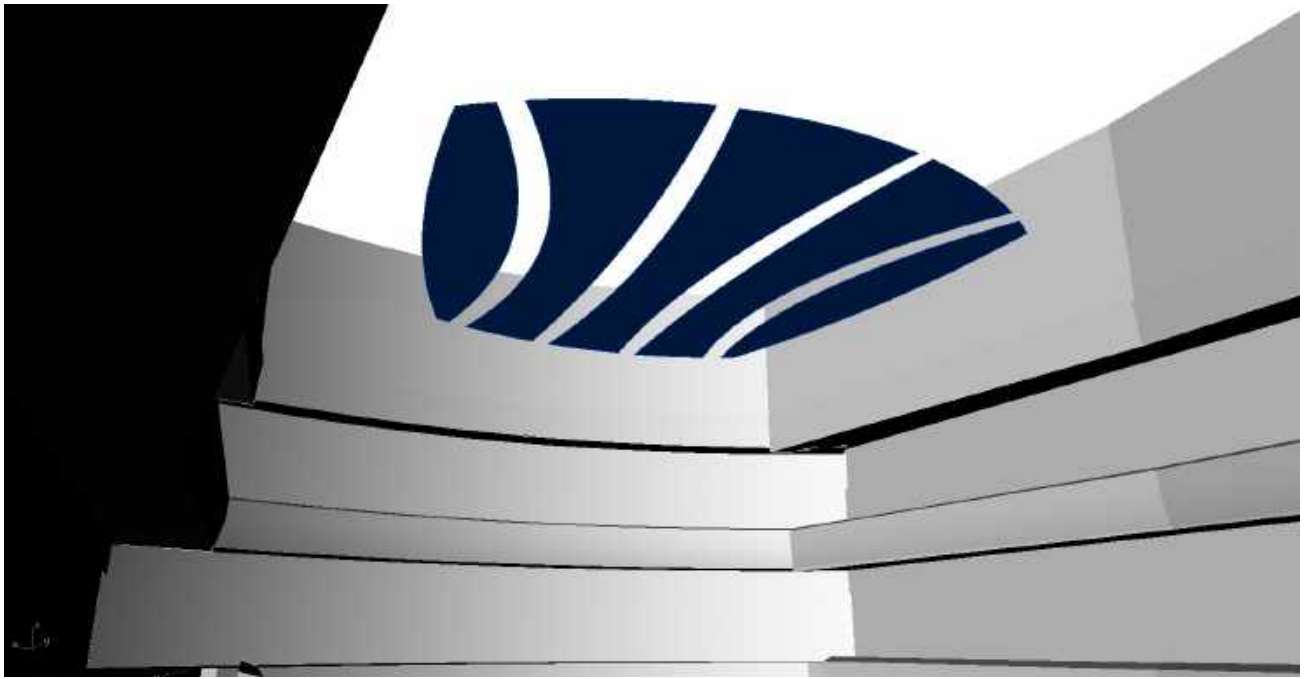


The center is covered by the lower soffit
The borders by the upper one.

5 – Getting away from the shoebox: canopy

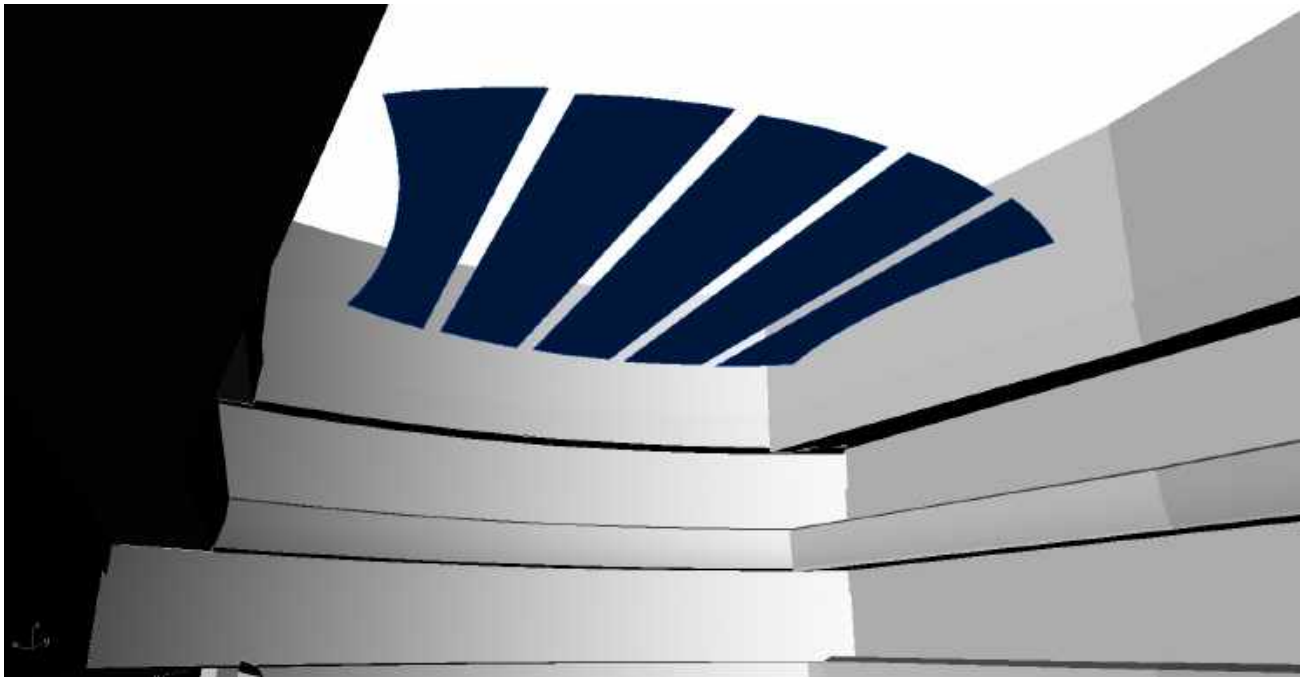




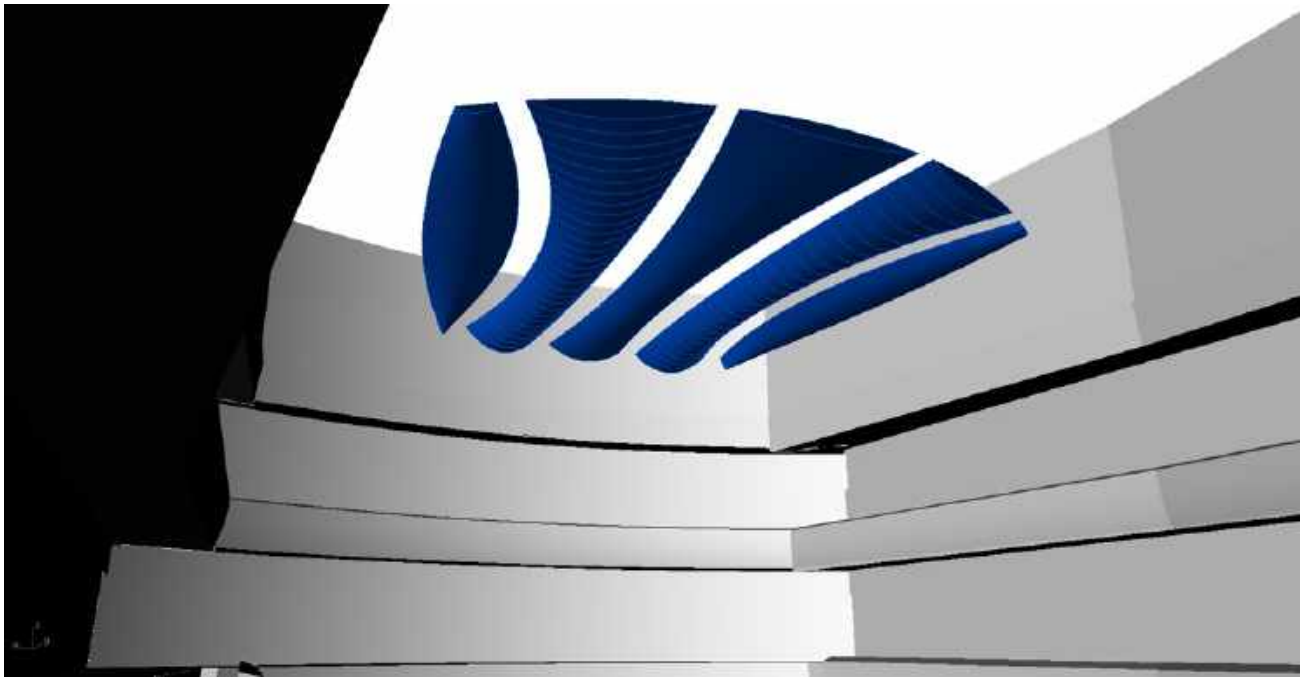


shape A - flat

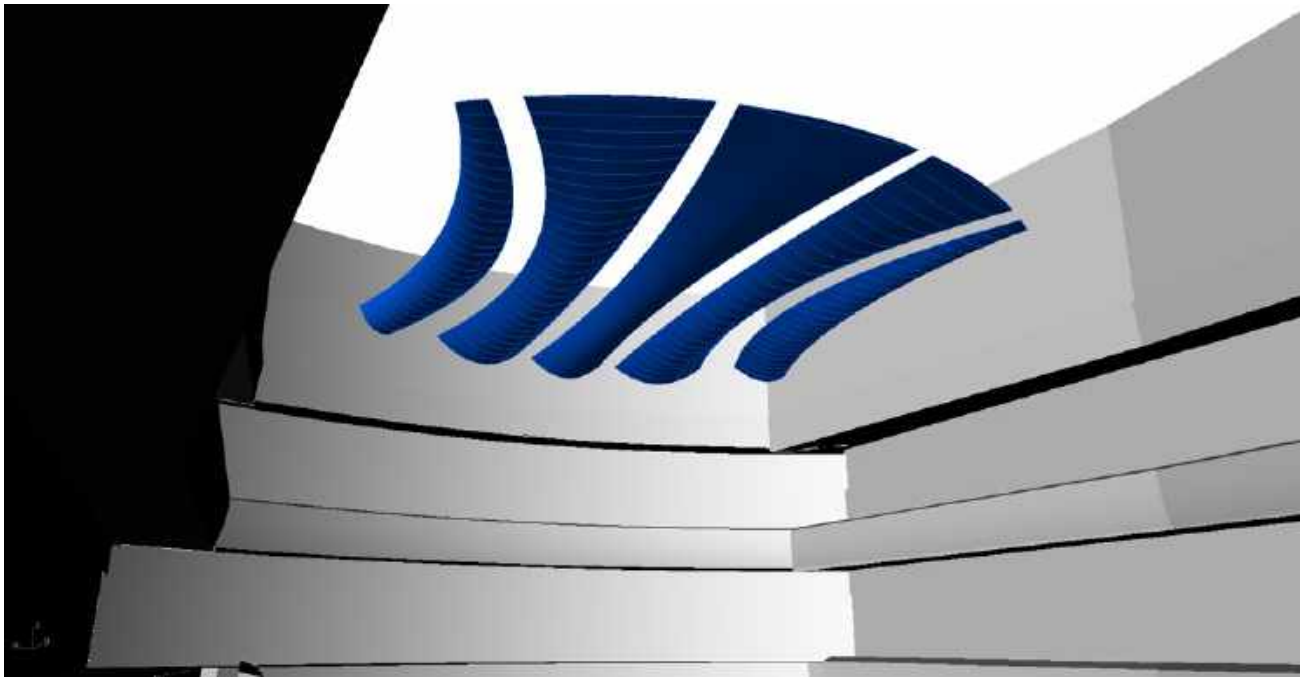
shape B - flat



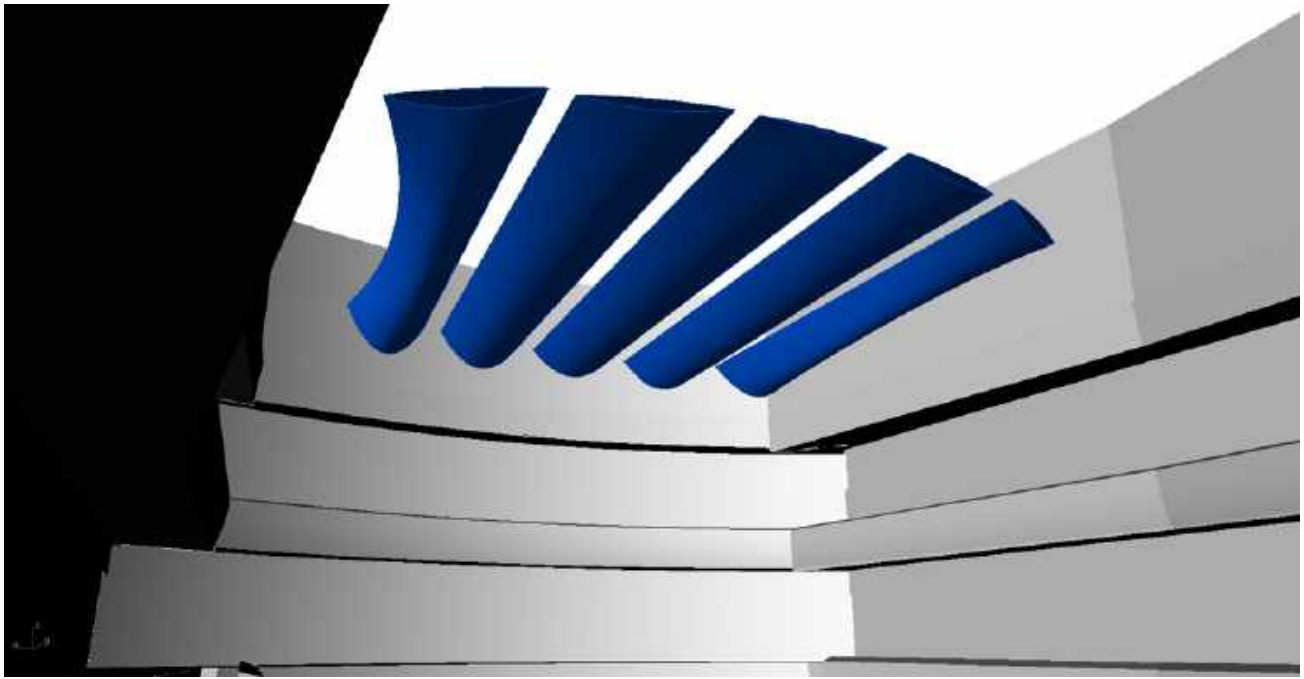
shape C - flat



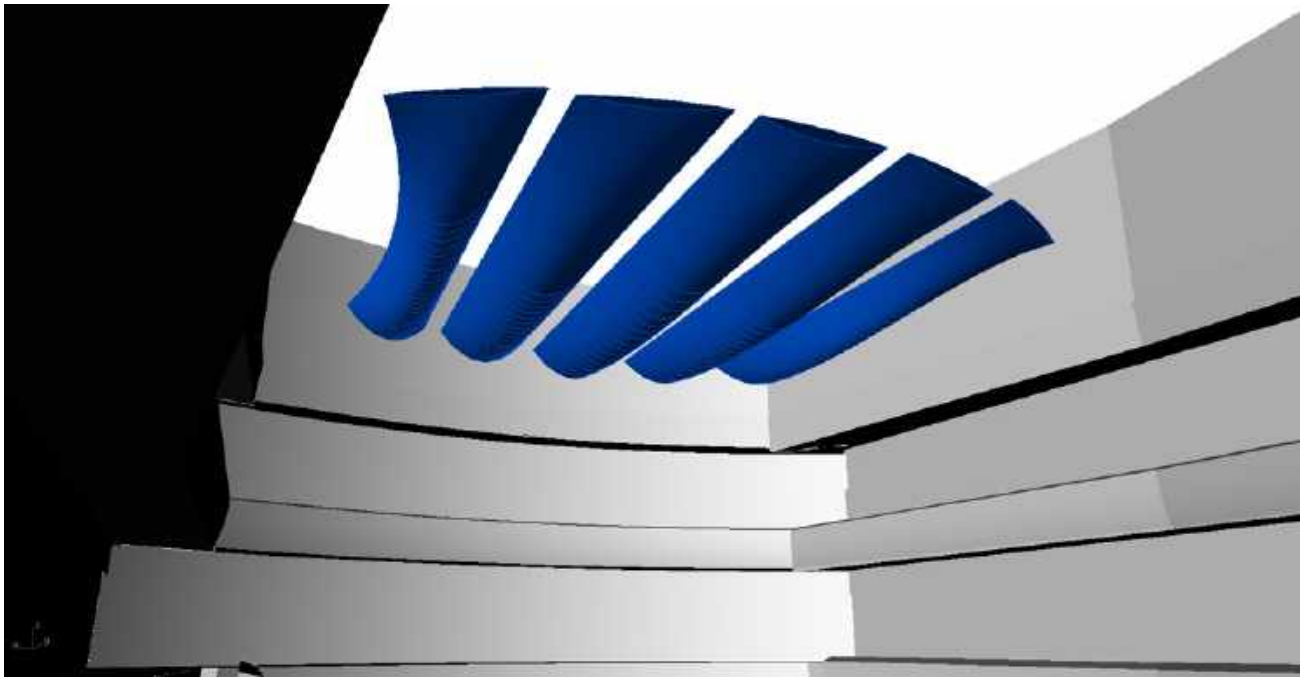
shape A – 3D



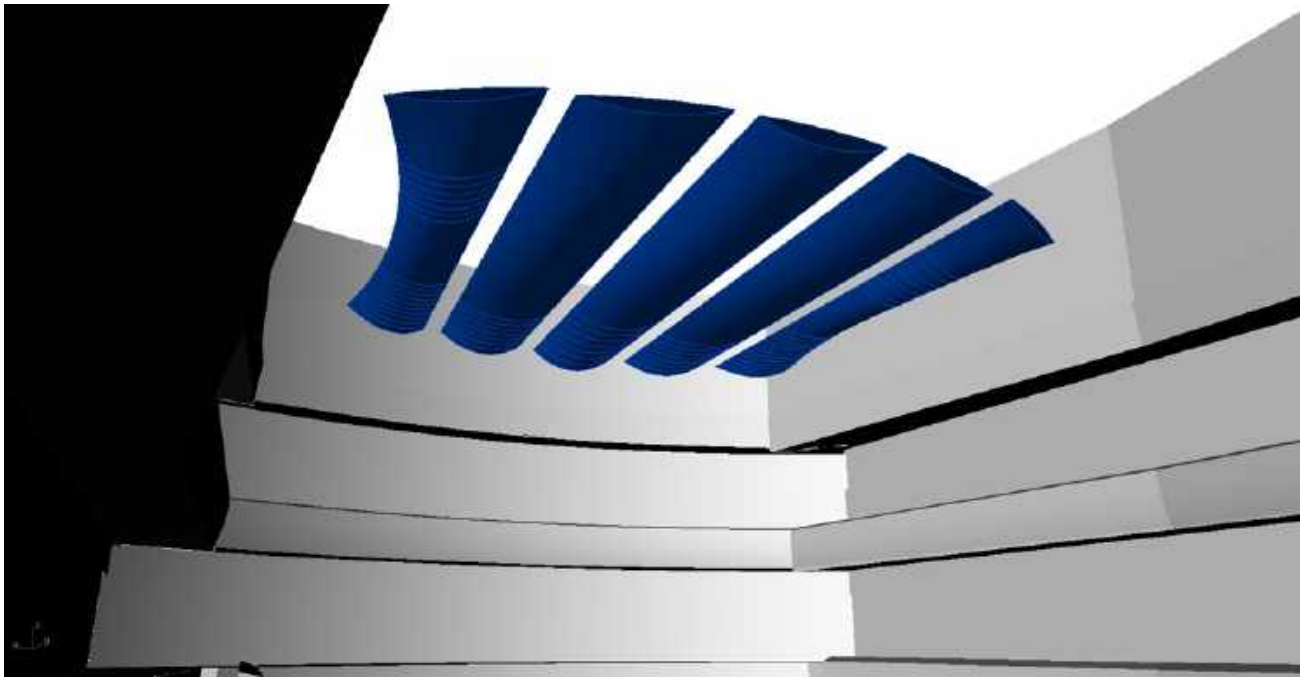
shape B – 3D



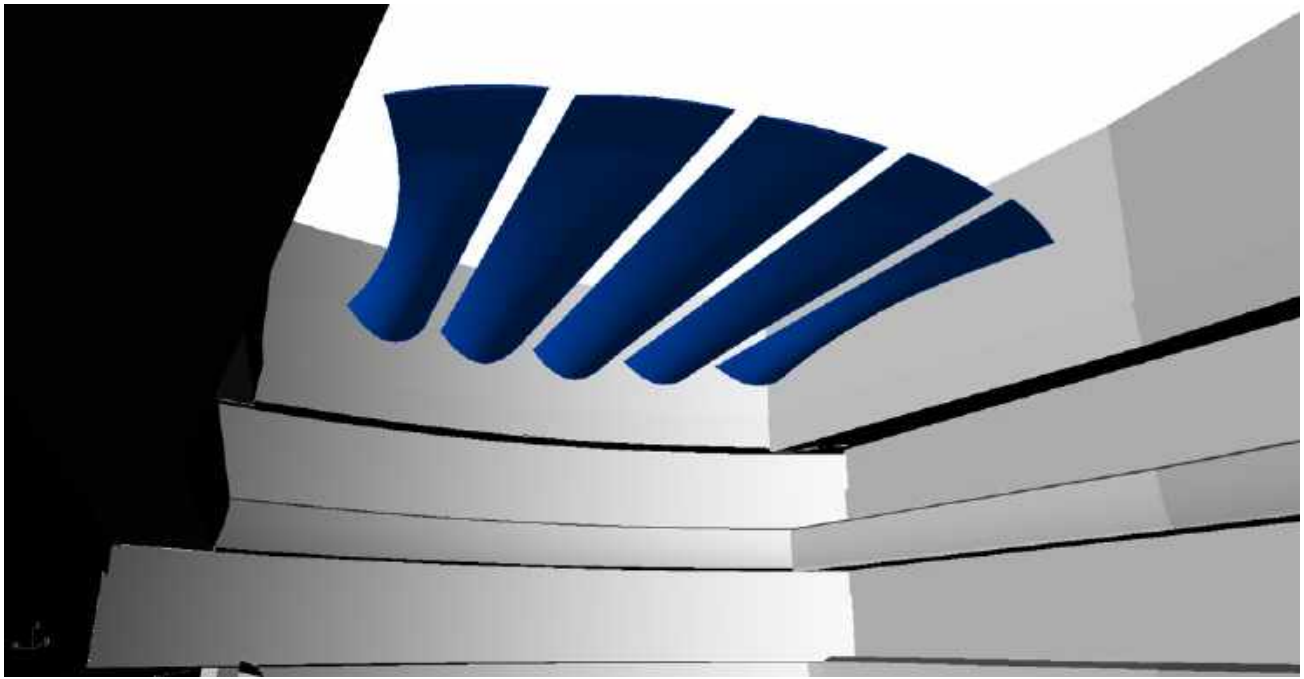
shape C – 3D variation 0



shape C – 3D variation 1



shape C – 3D variation 2

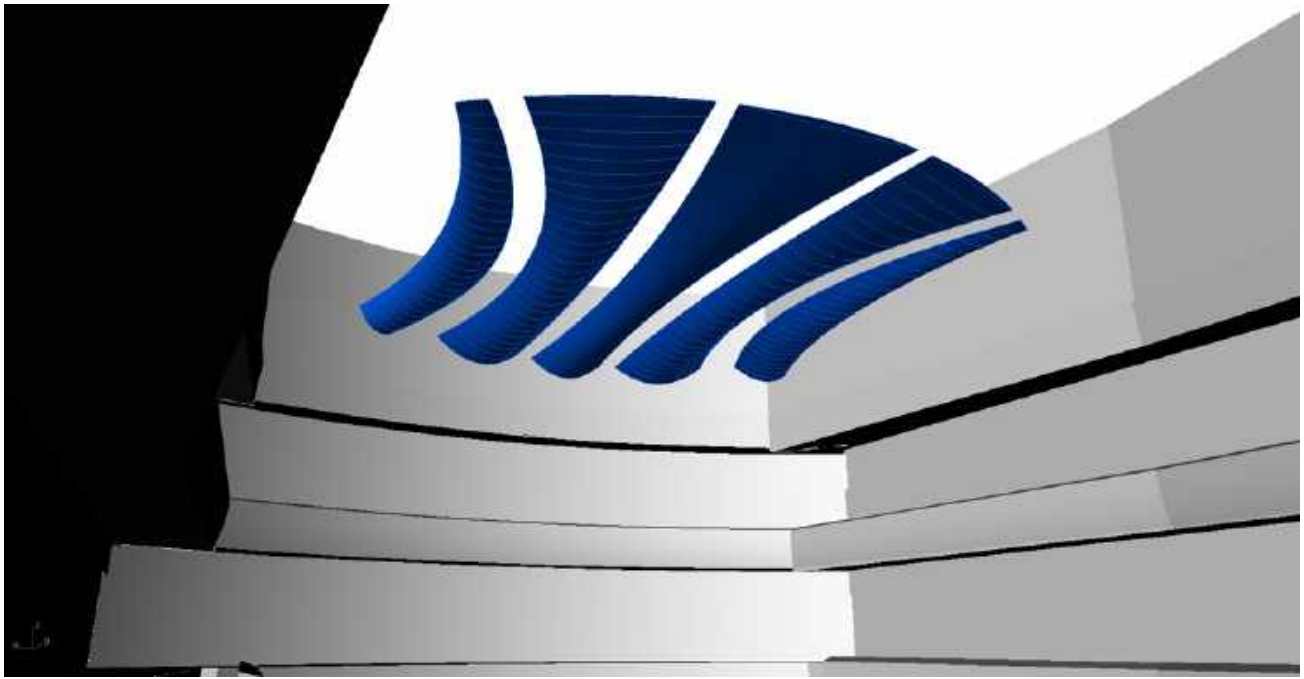


shape C – 3D variation 3

Flat – old shape

shape B - flat

3D – front flat, back curved in section



shape B – 3D

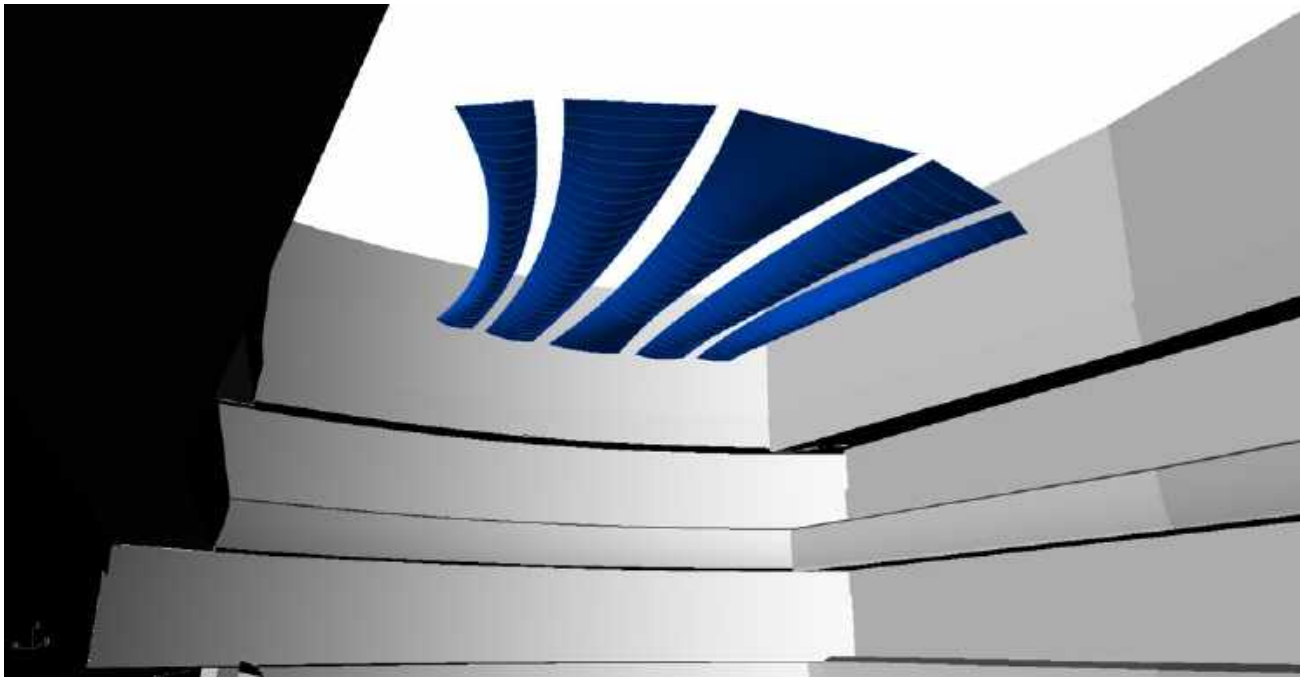
3D – front flat, back flat
(and straight panel edges)

shape B – 3D

3D – front flat, back slightly curved

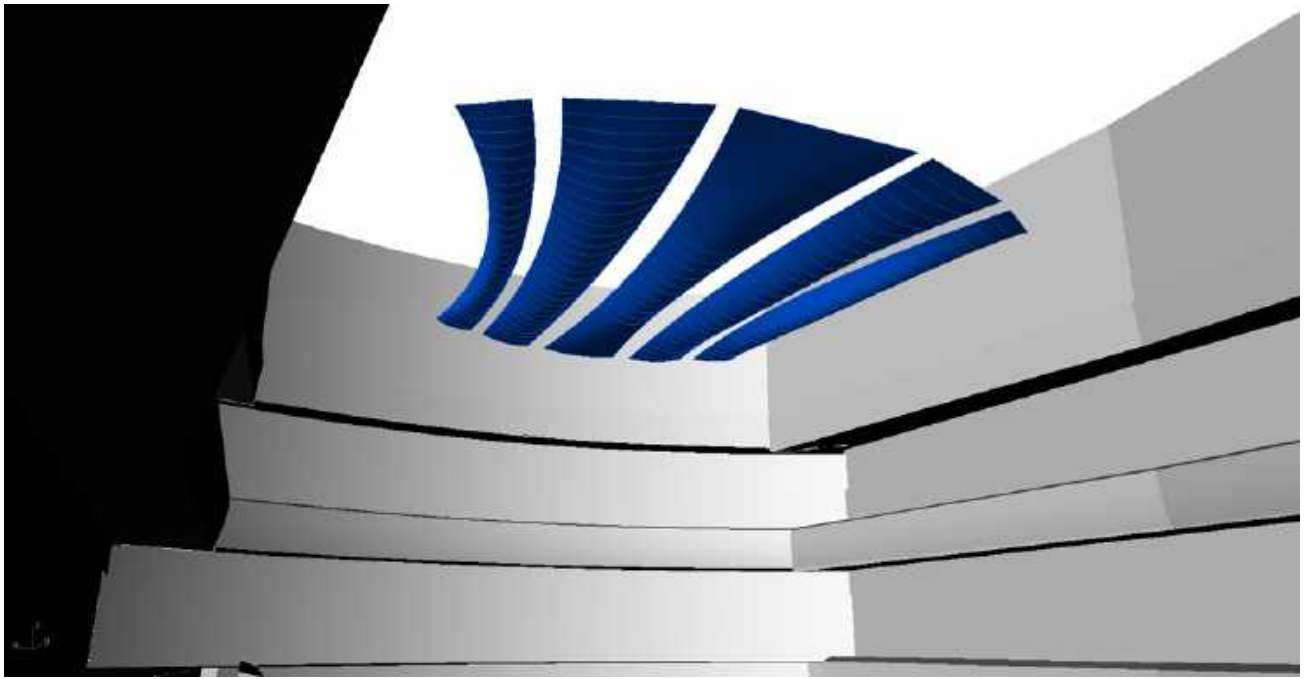
shape B – 3D

Shape changed – slim at back

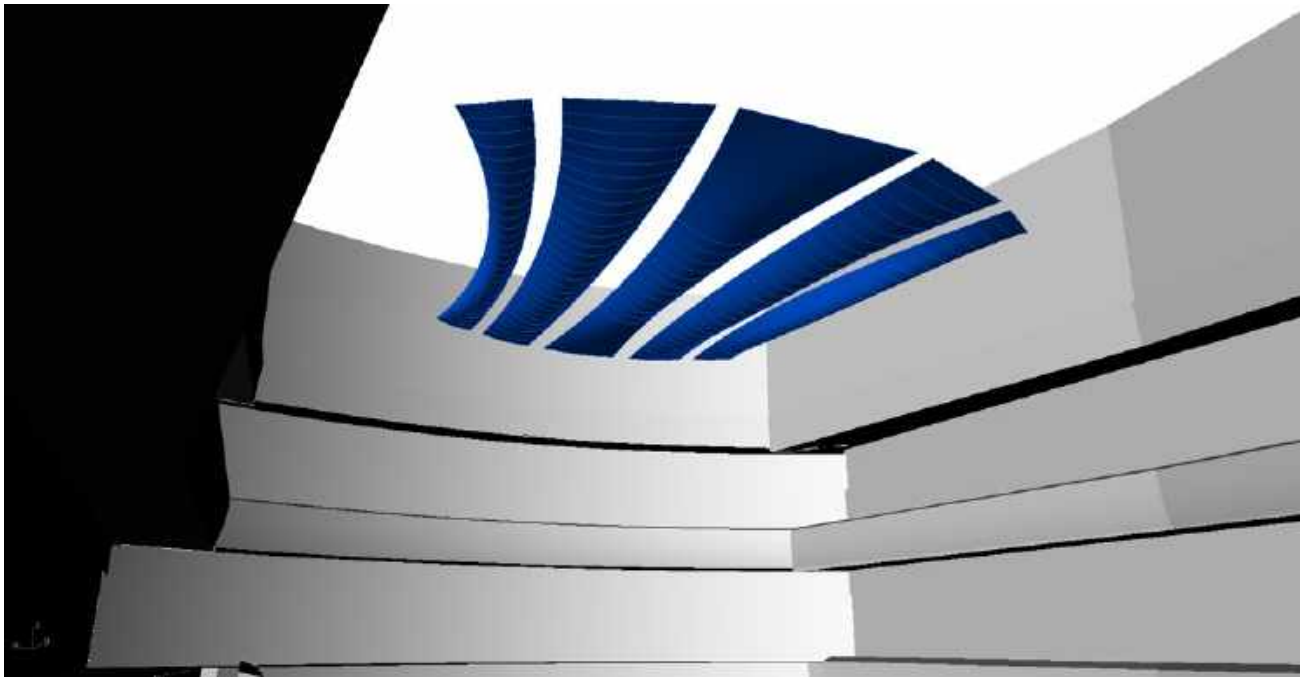


shape B – 3D

Back more curved in plan

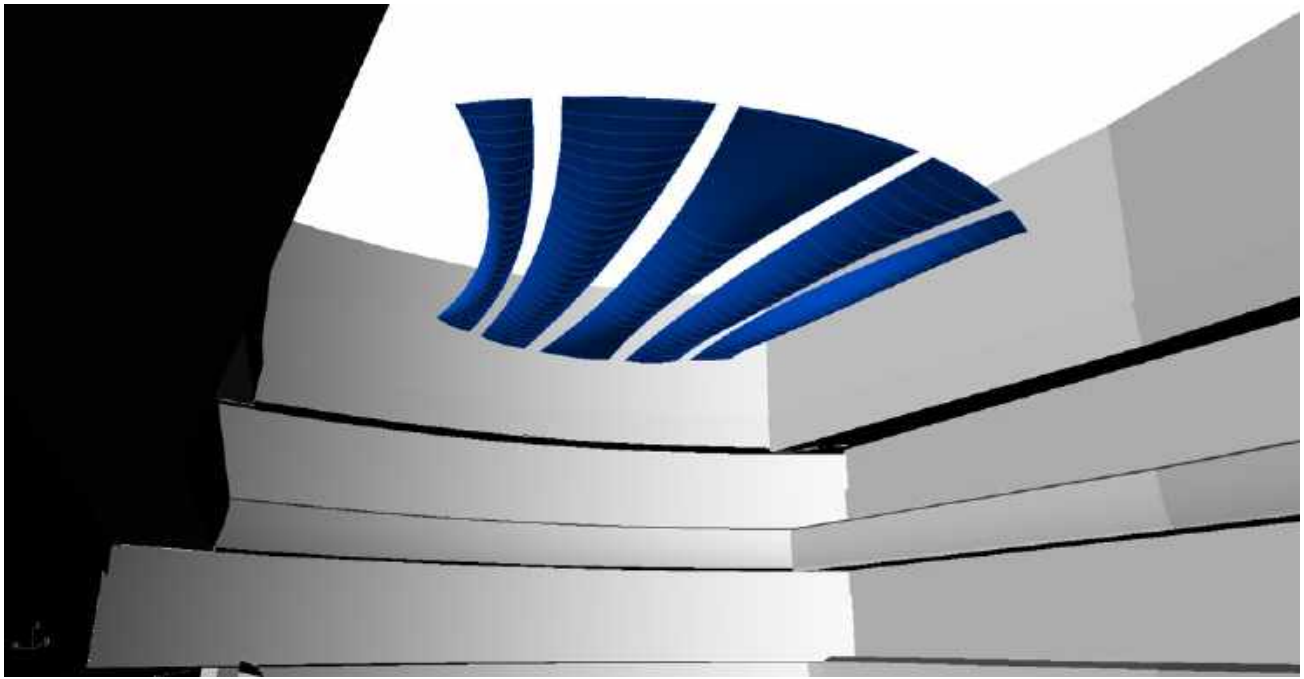


shape B – 3D



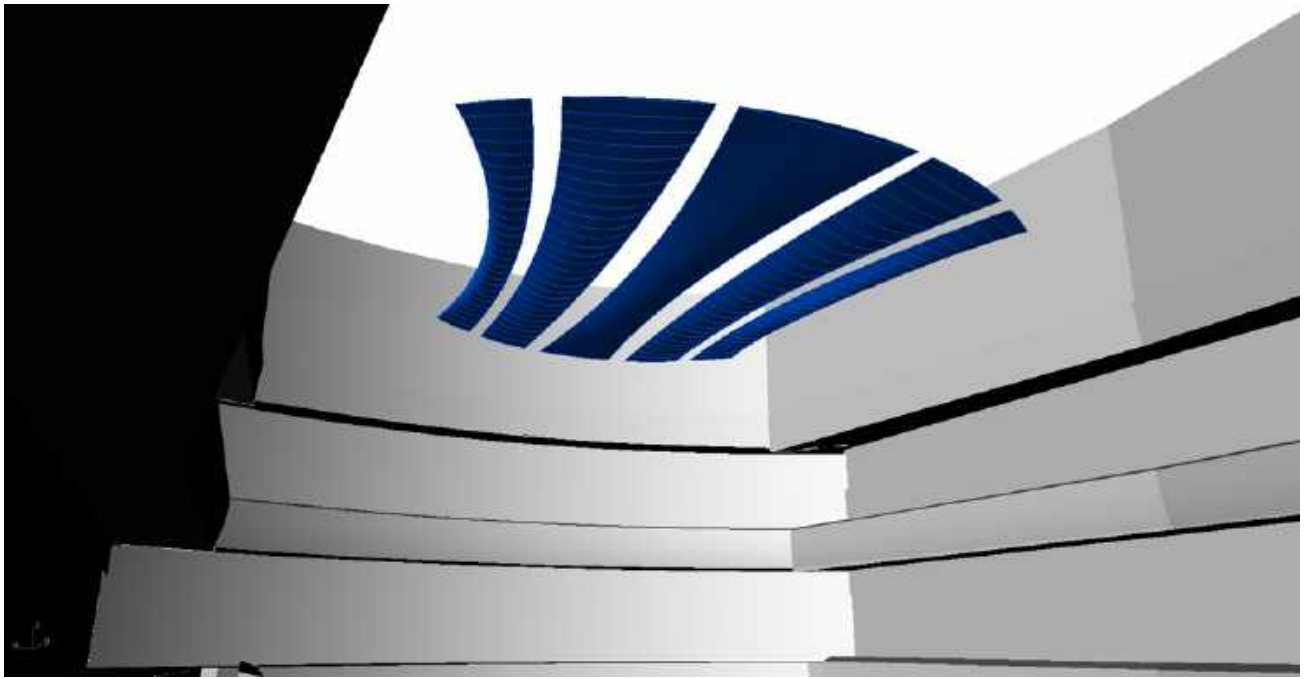
shape B – 3D

All front panel edges curved in plan

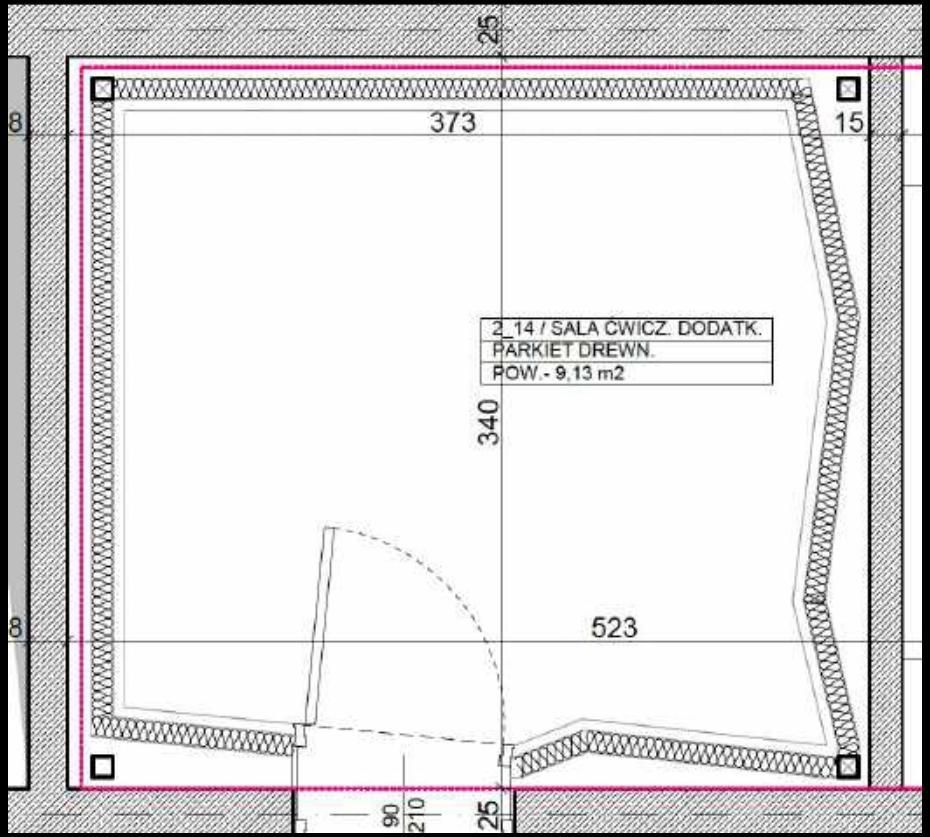


shape B – 3D

Less curved – more realistic…

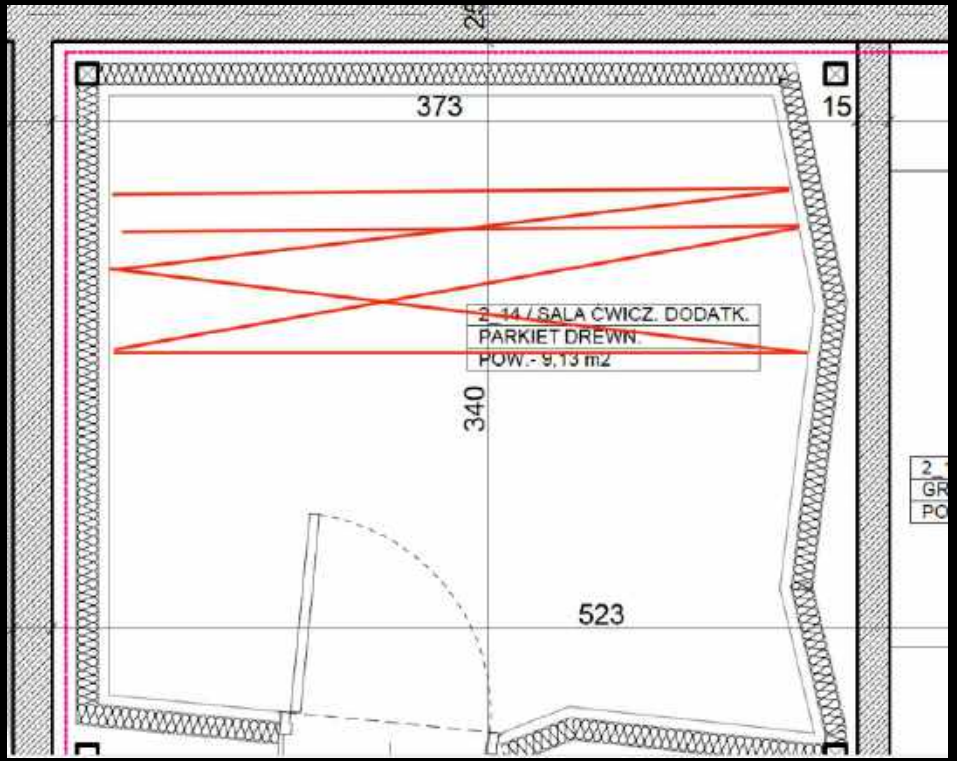


6 – Avoiding problems…



Anti-flutter-echo treatment, but are you sure it will work?

6 – Avoiding problems…



Better check before… otherwise there may be surprises…!

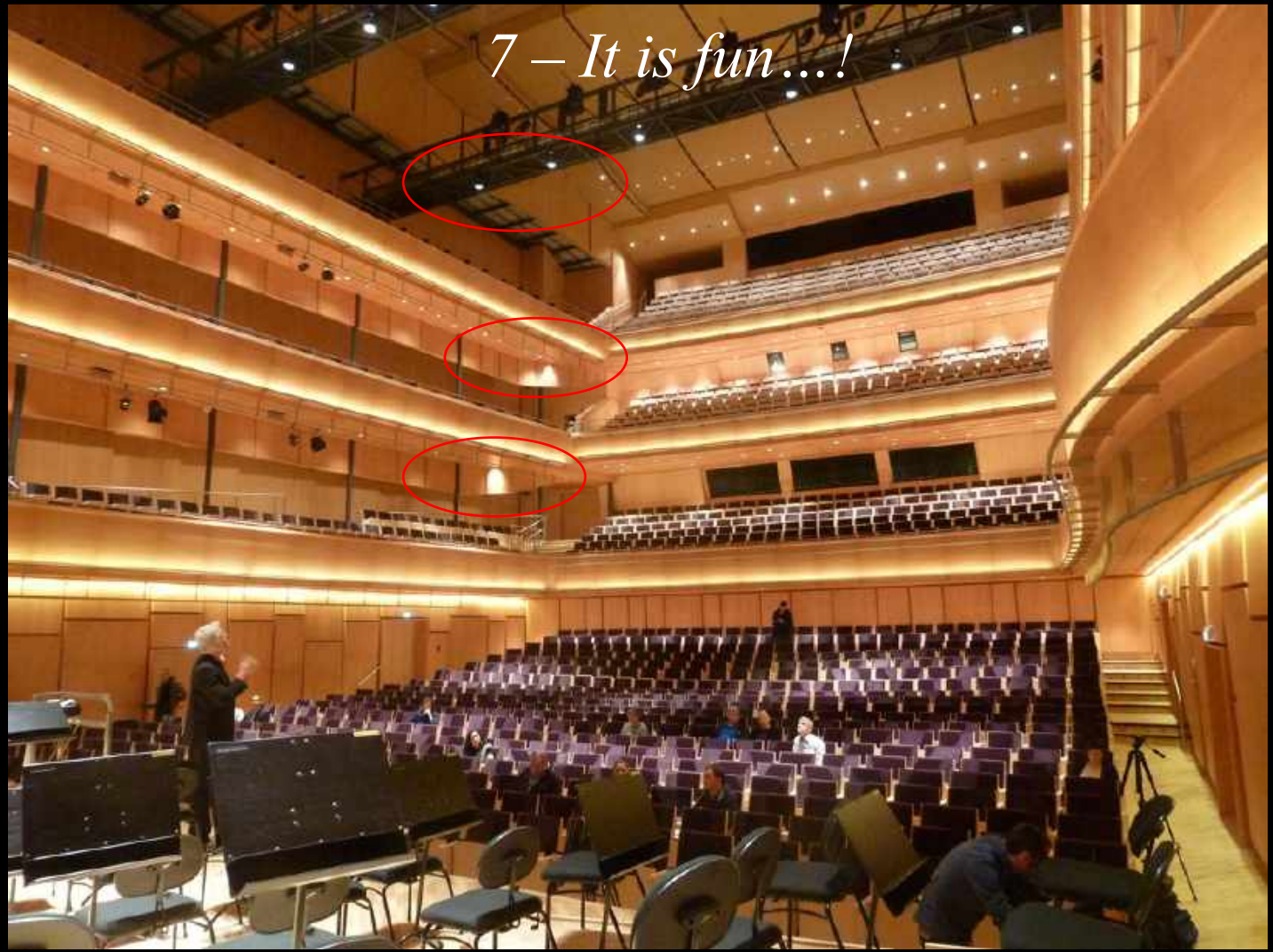
Summary and outlook

1. *Optimizing reflections is required and G is a key parameter*
2. *Playing billiard in shoeboxes is "easy", with 90° angles. But for playing billiard with non-90° angles, we do need computers… (at least I do…)*
3. *Curved surfaces create great opportunities for acoustic design – and for me curved surfaces are preferred acoustically over diffusing surfaces.*
4. *Every concert hall is different and should be different, and this will continue to be the case, including many designs that will try to go away from the classical shoebox.*
5. *Using interactive design tools for avoiding errors and fix problems before they are built should and needs to become the standard*
6. *Outlook: what about scattering?*


Some Concert Halls…
Caryatides in Musikverein Vienna
Columns in Amasterdam Concertgebouw

Congress Hall: Flutter echo with the path including the highly absorbing (≥90% open) ceiling, scattering by regular structure seems sufficient to create problems.

7 – It is fun…!



How to get lateral reflections into the centre seats of upper balconies… - a task nearly or fully impossible in standard 90° shoebox halls…

Introducing “ears” into side wall reflectors (and access points)…


Thank you!
Questions?

Concert Halls and Opera Houses: how to make them sound. The use of parametric design tools in room acoustics

14. DEGA-Symposium
"Interaktive Auralisierung für die Planung von Räumen"
12. November 2021

Questions???

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KahleAcoustics