

International Workshop in Ravenna, Italy 7-8 October 2021

*Space, Sound, and Senses - The Design of Liturgical Experience
in Sant'Apollinare in Classe and its Landscape*

Acoustics of the basilica of St. Irene in Istanbul and revival of the sound of a Byzantine chant

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Abstract

The acoustics of the ancient basilica of St. Irene in Istanbul was studied in the EU-project CAHRISMA. An acoustic computer model is used for reconstruction of sounds as they might have been heard in the church in ancient times. The problems related to the geometrical details of the room and the acoustical data for the surface materials are discussed. The modelling of the domes and other curved surfaces need special attention. Acoustical measurements are used for a fine tuning of the material data in the model of the church in the present state. Then the model is changed where necessary to reconstruct the acoustics as it might have been in ancient times.

By means of the so-called auralisation-technique it is possible to listen to sounds in the room model, if the sound is recorded in an anechoic environment. Recordings have been made for this purpose of a reconstructed Byzantine 'Alleluia' with solo and choir dating from around 950 CE. The music is transcribed from manuscripts located in the library of the Vatican. The music was recorded with two singers in the anechoic room of the Technical University of Denmark. A newly developed technique was used to create the effect of a choir with many singers. The results can be listened to either through headphones or through a surround setup of loudspeakers.

Outline

- The St. Irene church and the CAHRISMA project
 - Acoustical measurements
 - Acoustical model
 - Virtual reconstruction
- Room models - Optimization of degree of detail
- The auralisation technique
 - The traditional Byzantine chant '*The Prophets from Heaven*'
- Reconstruction of the Byzantine '*Alleluia*'
 - Anechoic recordings
 - Creation of chorus
 - Listening examples

CAHRISMA Project

- **EU research programme: Protecting Europe's Cultural Heritage through EU Technological Research**
- EU Research Project ICA3-1999-00007 (CAHRISMA)
 - Conservation of the Acoustical Heritage by the Revival and Identification of the Sinan's Mosques Acoustics
 - 1 February 2000 – 31 January 2003
- Virtual restoration and revival of cultural heritage
 - Visualization of architecture and human beings
 - Acoustic measurements and simulations
 - Integrated acoustic and visual models

CAHRISMA – 7 partners

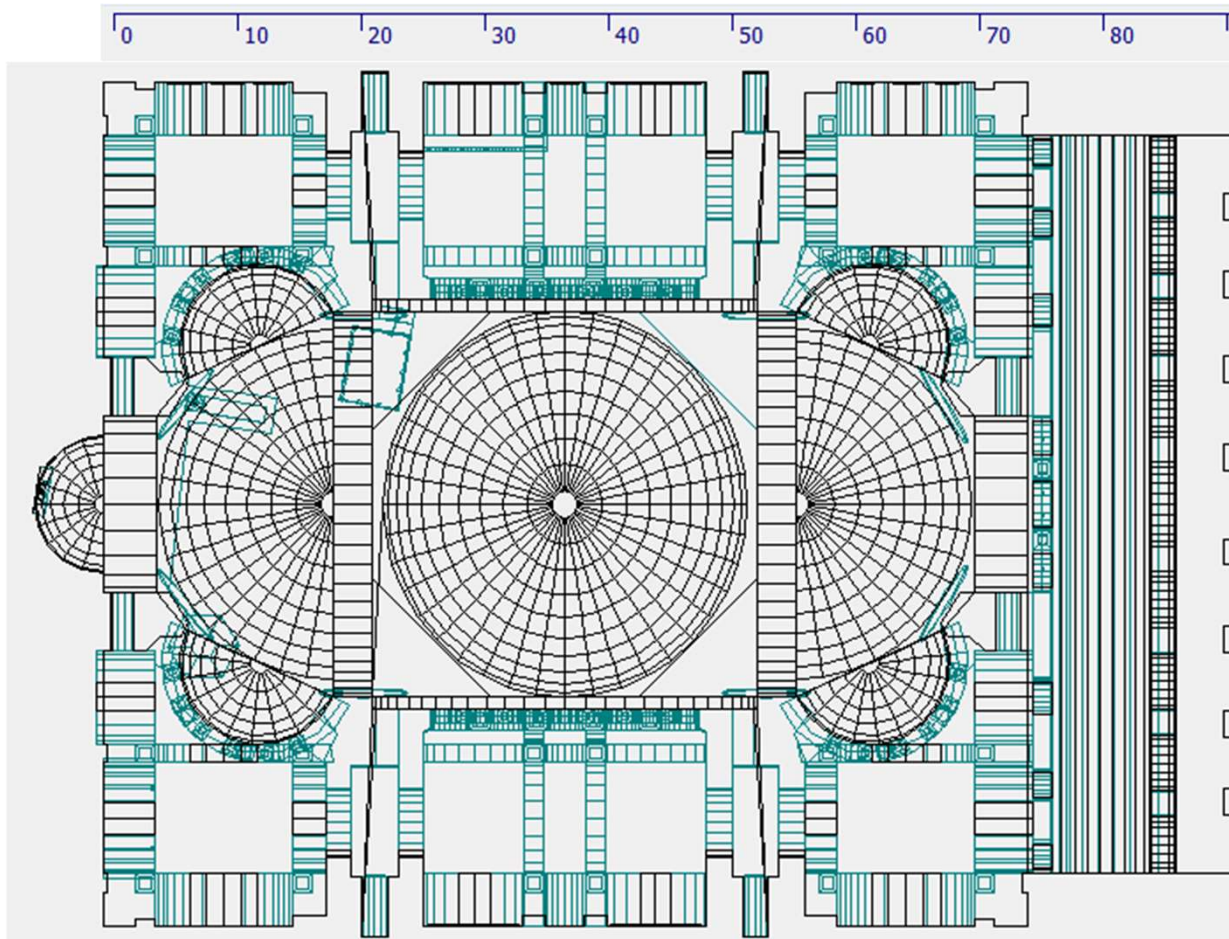
- DTU - Technical University of Denmark, **Denmark**
- YTU - Yildiz Teknik Universitesi, **Turkey**
- UNIFE - Universita degli Studi di Ferrara, **Italy**
- EPFL - Ecole Polytechnique Fédérale de Lausanne, **Switzerland**
- UNIGE - Université de Geneve, **Switzerland**
- AEDIFICE – Association d’Etude pour le Développement, l’Information, la Formation et l’Intervention sur le Cadre de Vie et l’Environnement, **France**
- UOM - University of Malta, **Malta**

CAHRISMA - Selected buildings

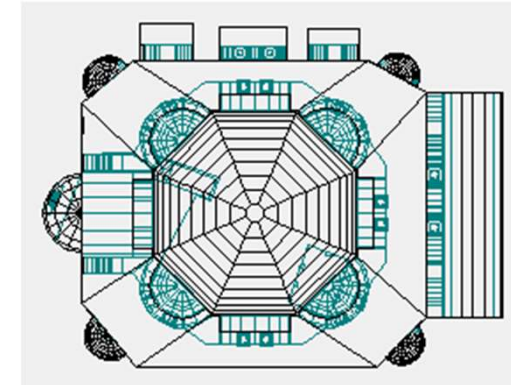
- Three Byzantine churches
 - St Irene Church (ca. 330, 548)
 - Ss Sergius and Bacchus Church (536) *
 - Hagia Sophia (537)
- Three of Sinan's mosques
 - Süleymaniye Mosque (1557)
 - Sokullu Mosque (1572)
 - Selimiye Mosque, Edirne (1574)

*) Architecturally very similar to San Vitale, Ravenna (547)

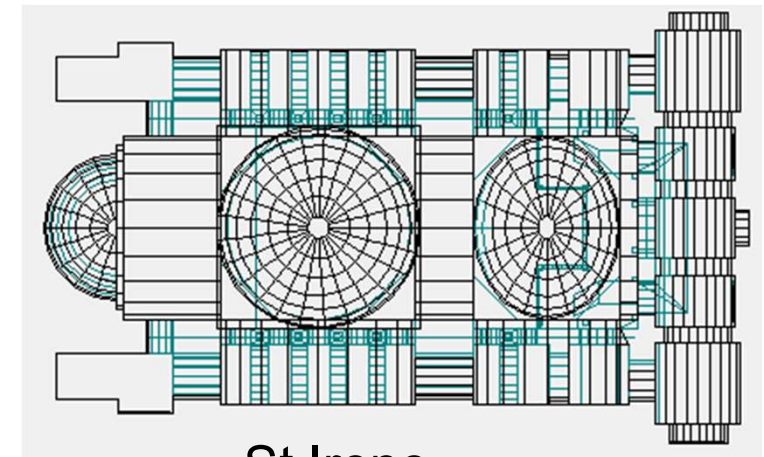
Churches



Hagia Sophia



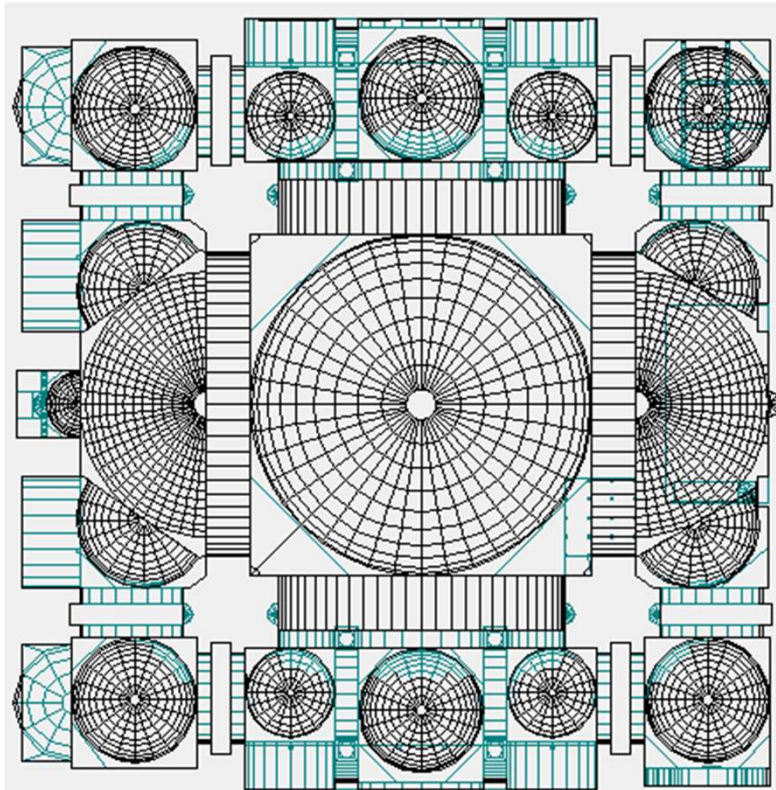
Ss Sergius
and Bacchus



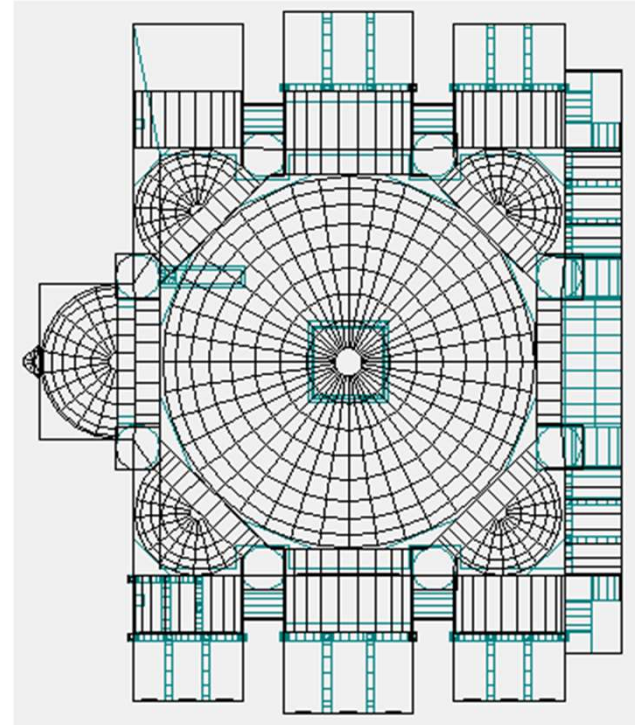
St Irene

Sinan mosques

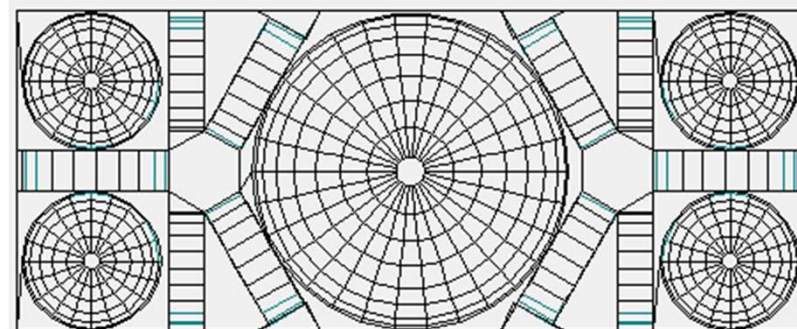
0 10 20 30 40 50 60 70 80 90 100 110 120 metres



Süleymaniye



Selimiye



Sokullu

CAHRISMA project

Acoustical
measurements
in Hagia Sophia
October 2000 by the
team from DTU



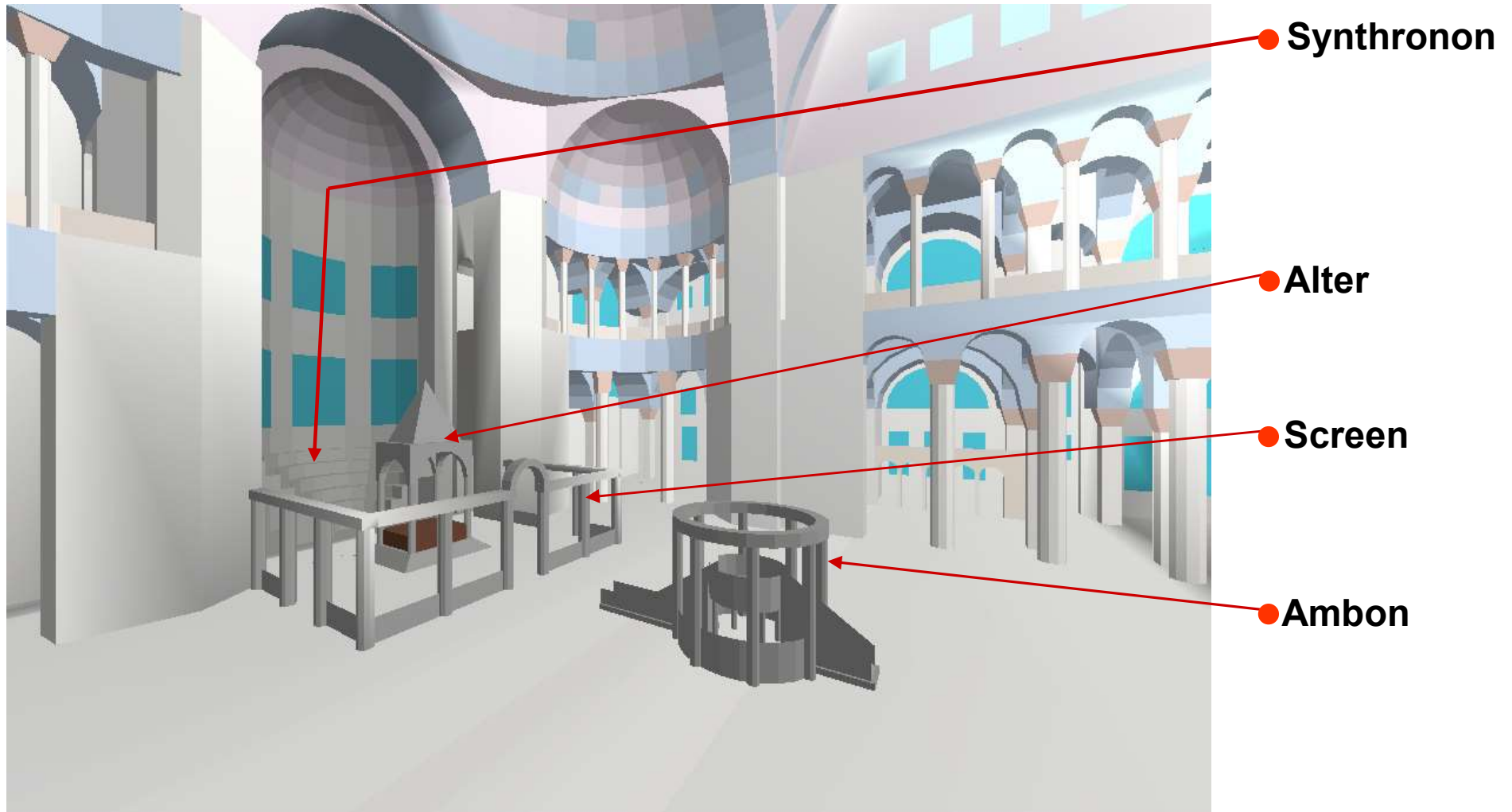
The room and the acoustical model



Photo: J.H. Rindel



Hagia Sophia as a Byzantine Church



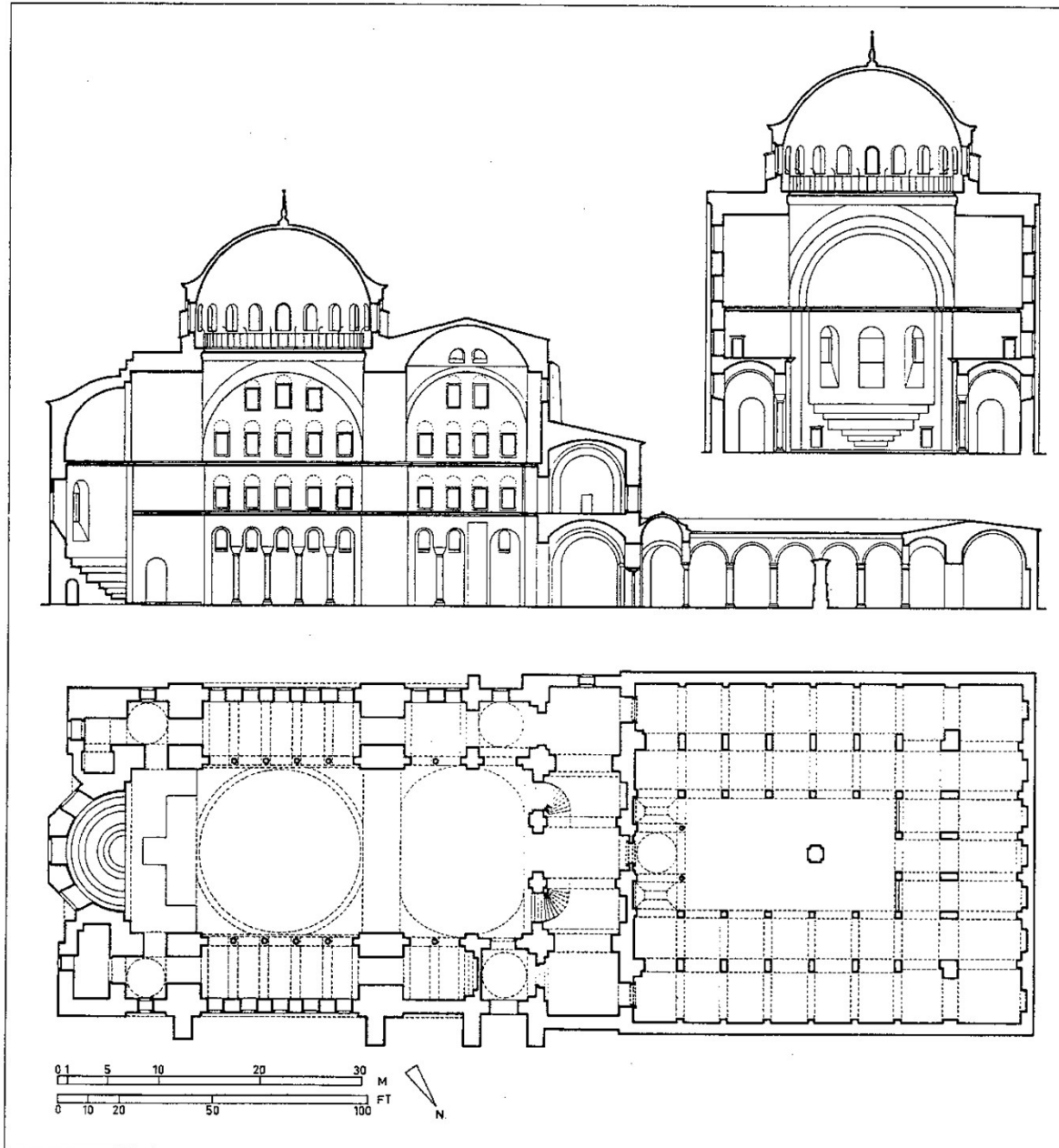
Weitze & Rindel: Revival of the Acoustics of Mosques and Byzantine Churches.
CAHRISMA Workshop, Istanbul 17 December 2002. Proceedings pp. 11-15.

St. Irene church, Istanbul



Photo: J.H. Rindel

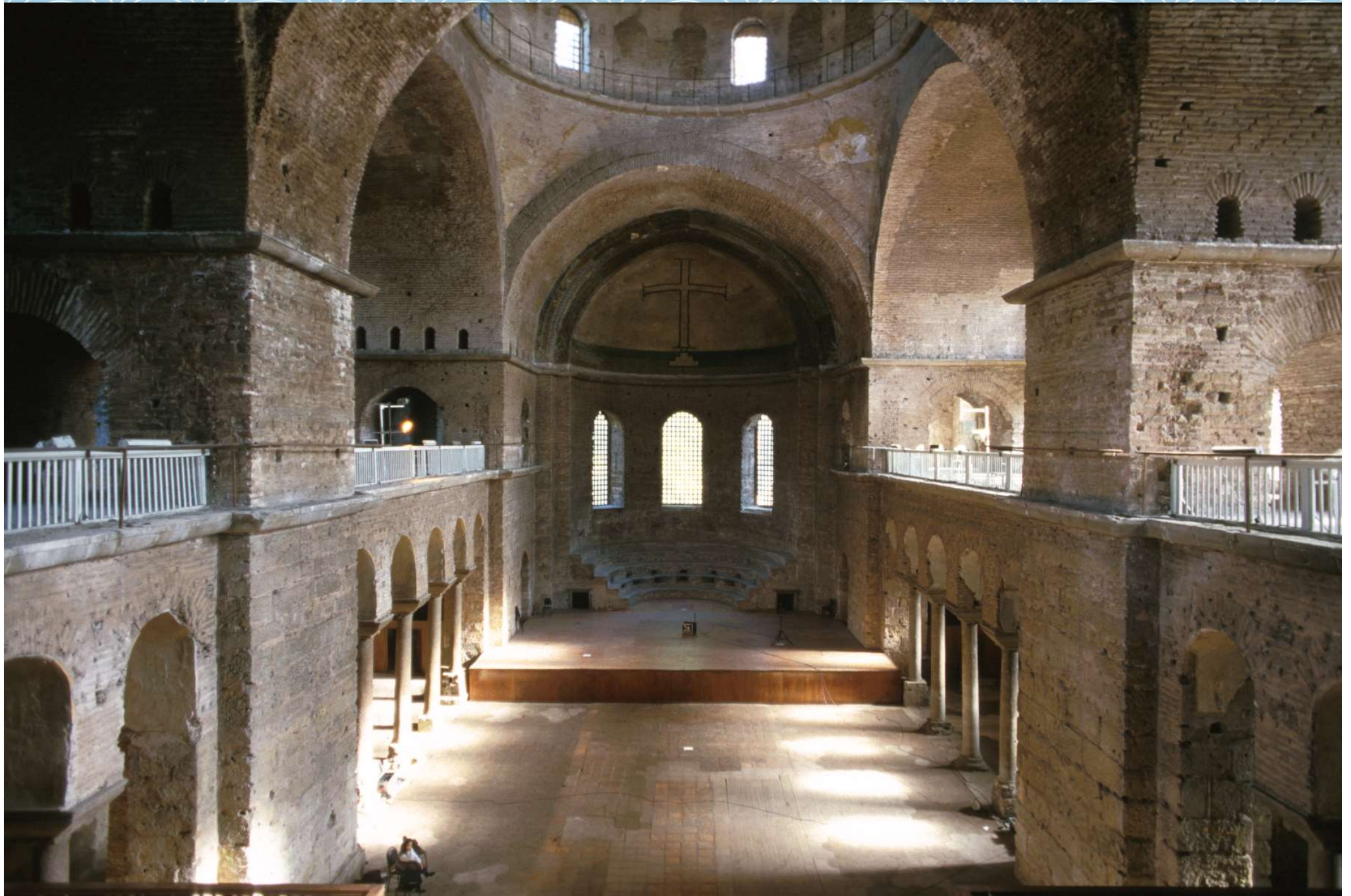
St. Irene church



Originally from
around 330, rebuild
548

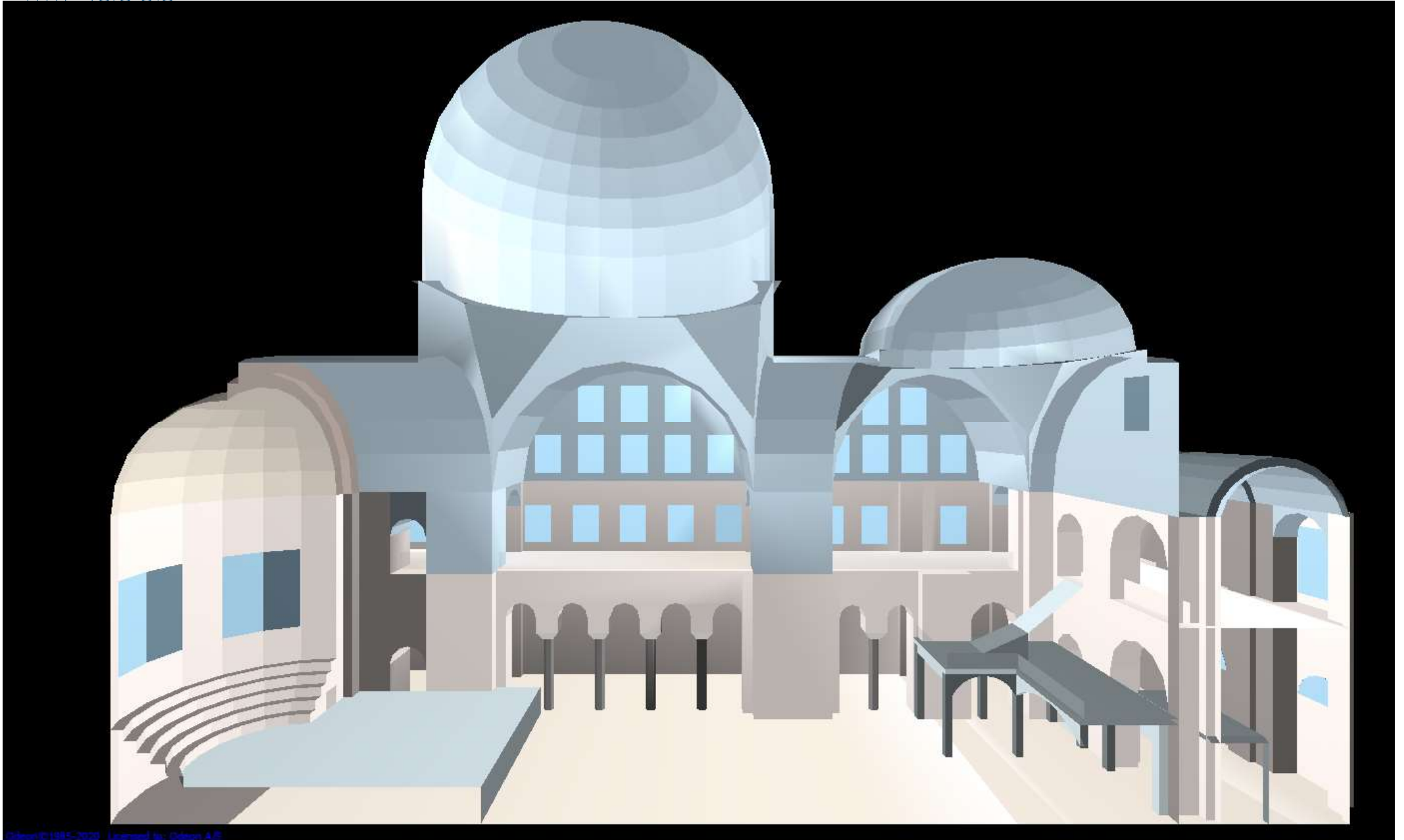
Other uses after
1453

Today it is used for
concerts

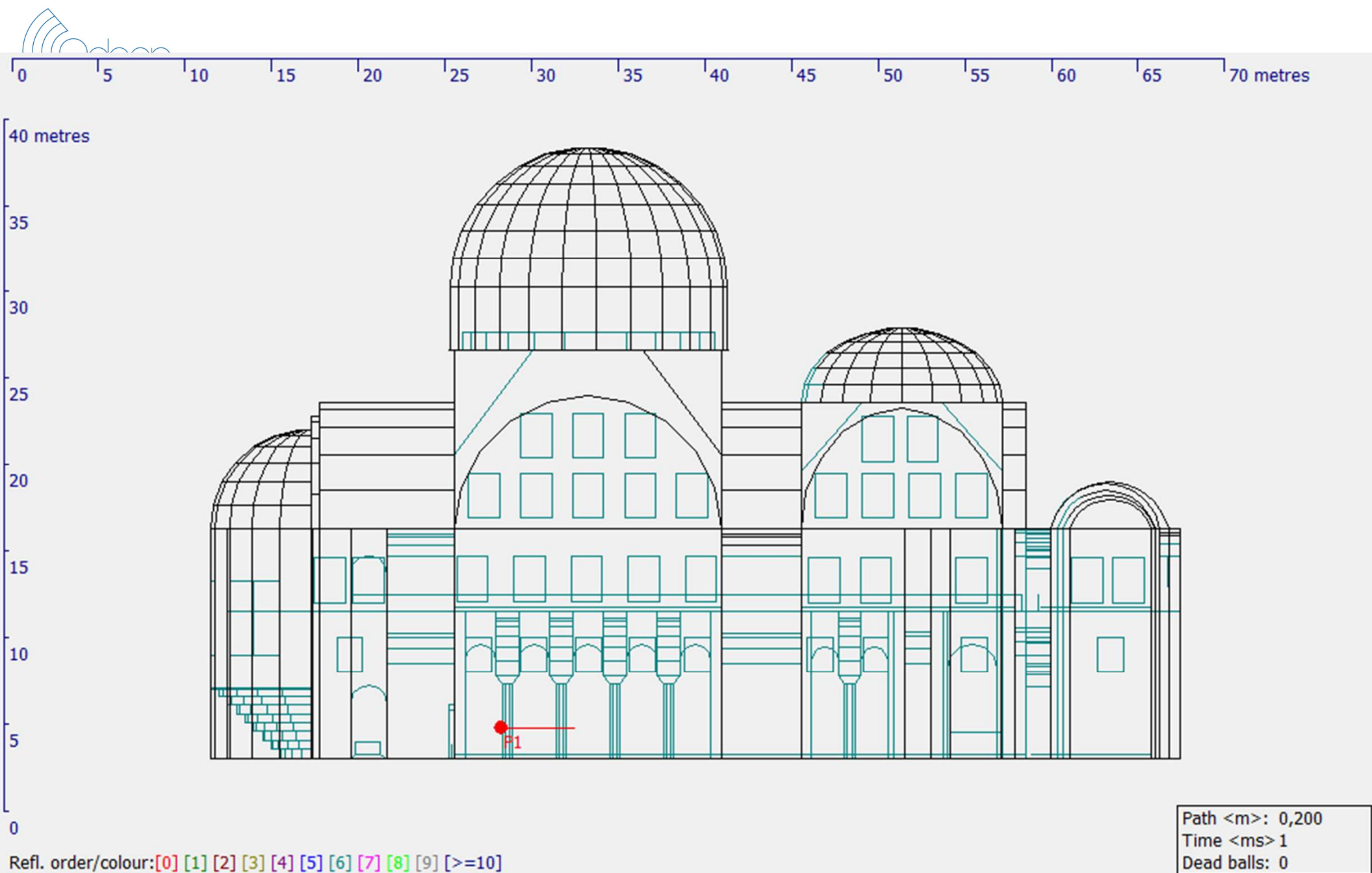




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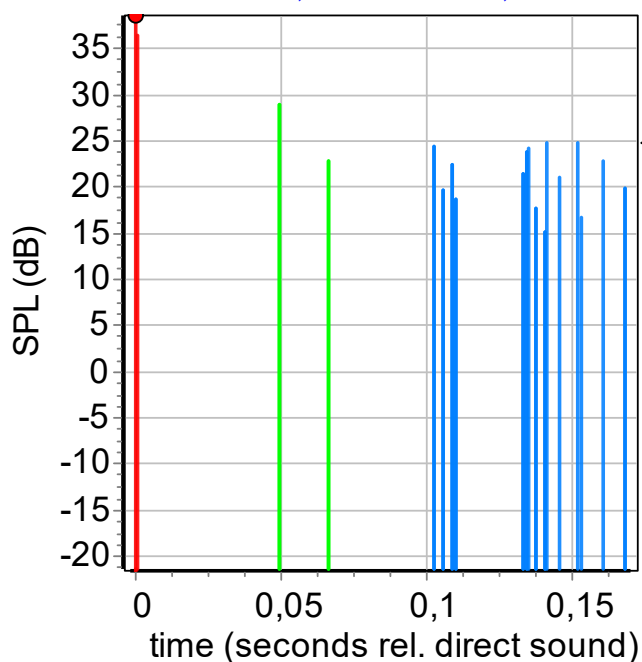
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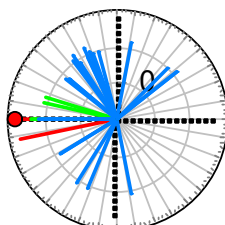
Room acoustic calculations

Reflectogram

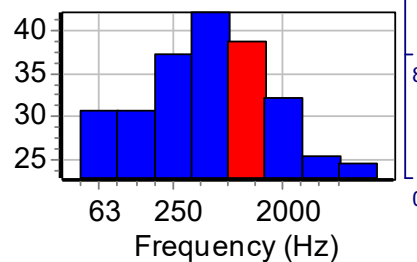
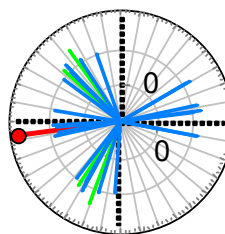
Arrival time: 43,81 ms (0,00 ms rel. direct or first ref)
 Level of: 38,61 dB (0,00 dB rel. direct)
 Azimuth angle: 7,59°, elevation angle: 0,00°
 Reflection: 0. order, 1. reflection of 30, source:1



Elevation

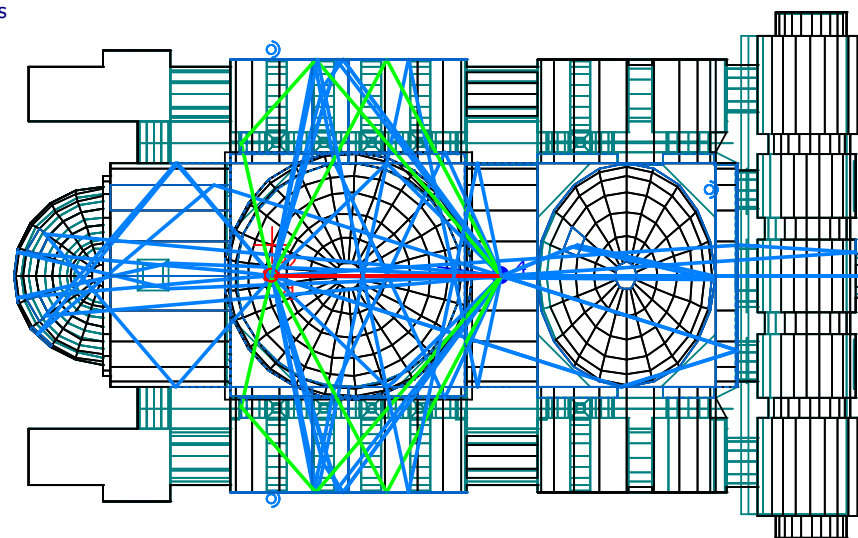


Azimuth



0 10 20 30 40 50 60 metres

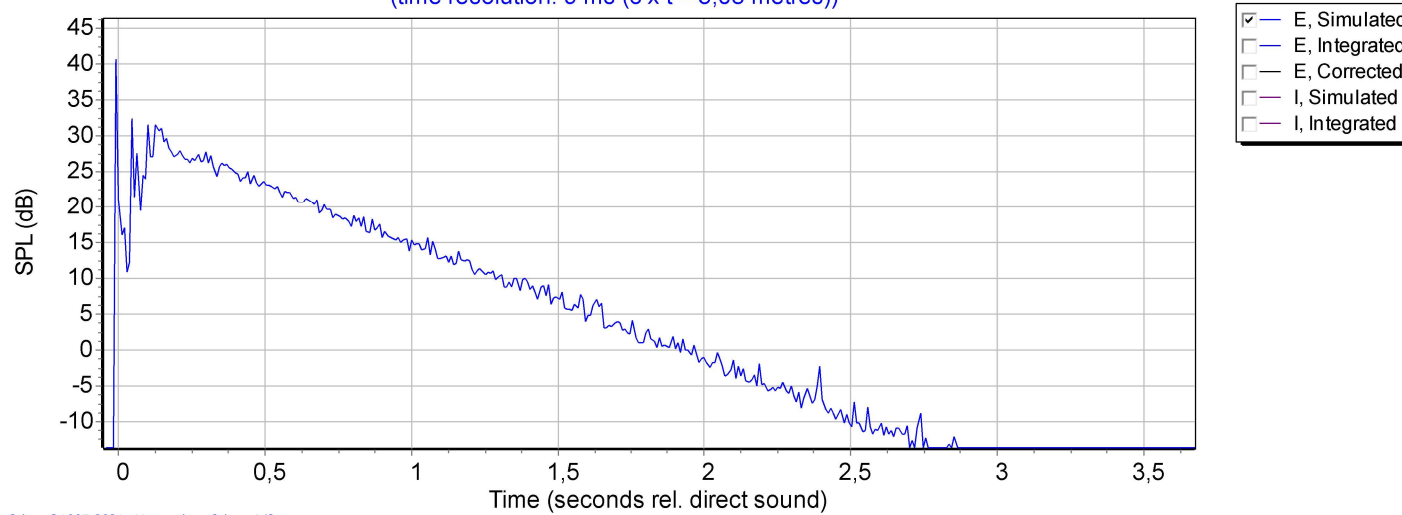
40 metres



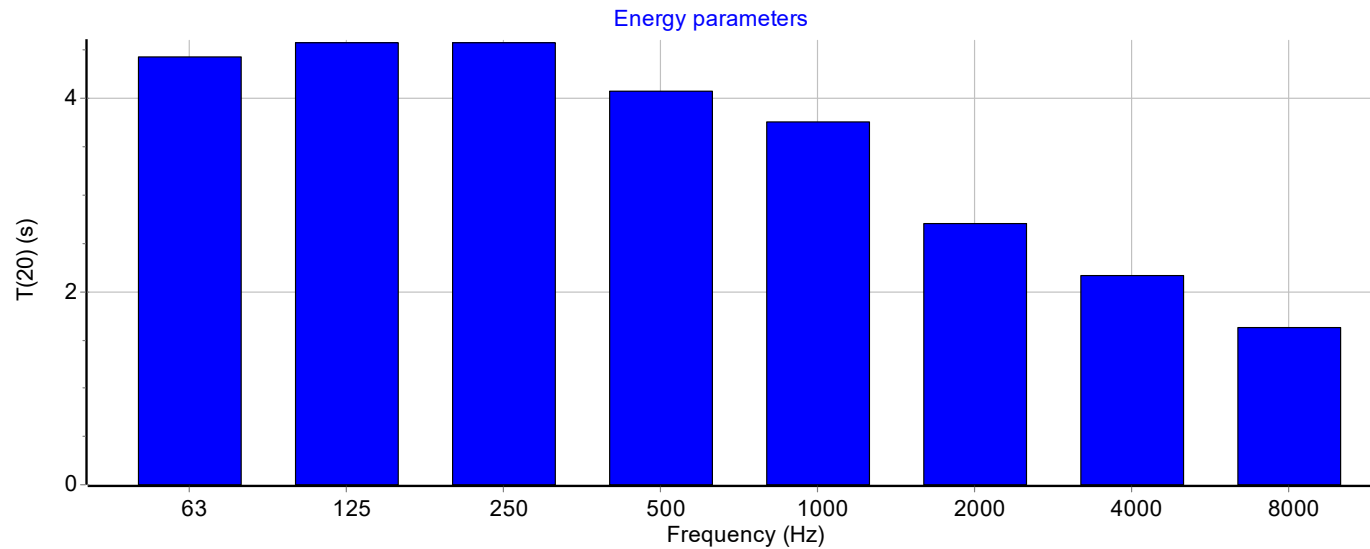
Scale: Music
 Time rel. direct
 200-∞ ms
 80-200 ms
 20-80 ms
 2-20 ms
 0-2 ms

Room acoustic calculations

Decay curves at 1000 Hz, $T(30)=3,73$ s at 1000 Hz
(time resolution: 9 ms (c x t = 3,08 metres))



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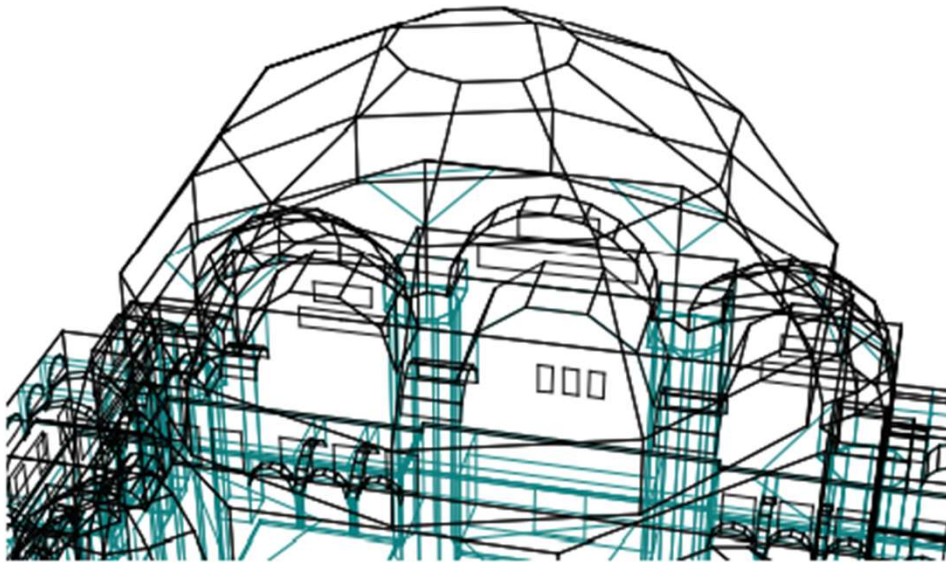
Optimization of degree of detail

Example: The Selimiye mosque in Edirne

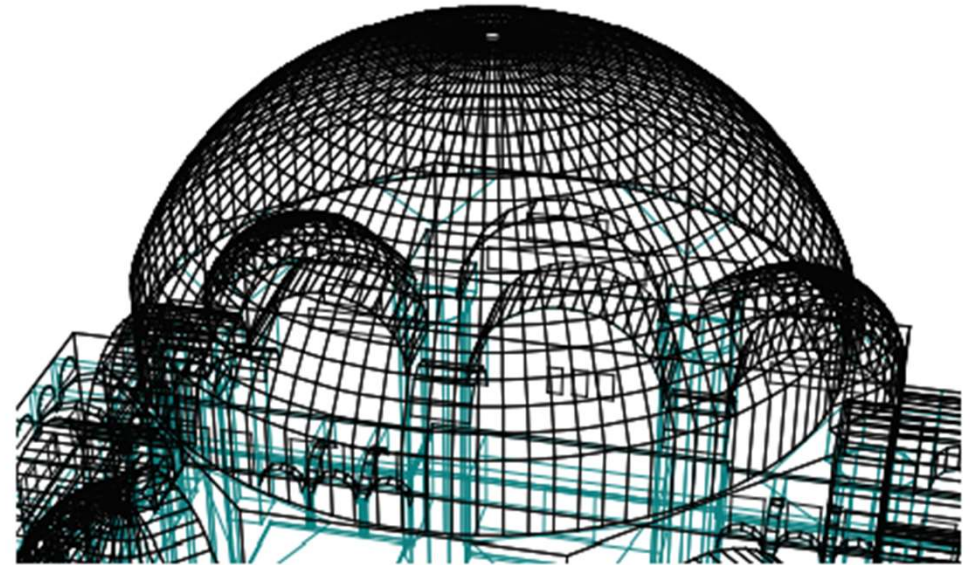


Ref: Koutsouris, Nørgaard, Christensen, Rindel: Discretization of curved surfaces and choice of simulation parameters in acoustic modelling of religious spaces. Proceedings of ICSV 23, 2016, Athens, Greece.

Discretizations of the main dome



(a) $(M, N) = (10, 5)$.

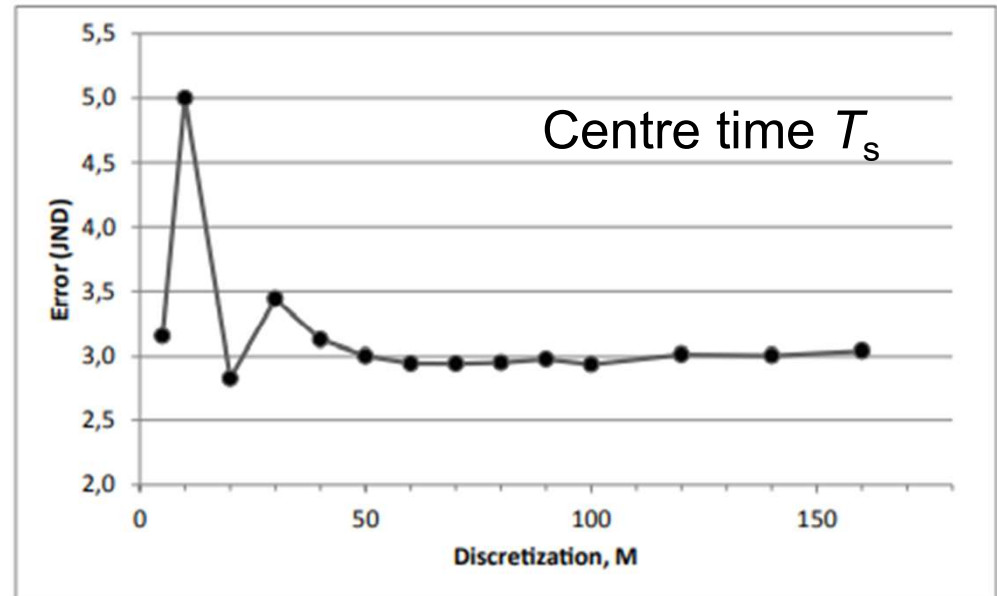
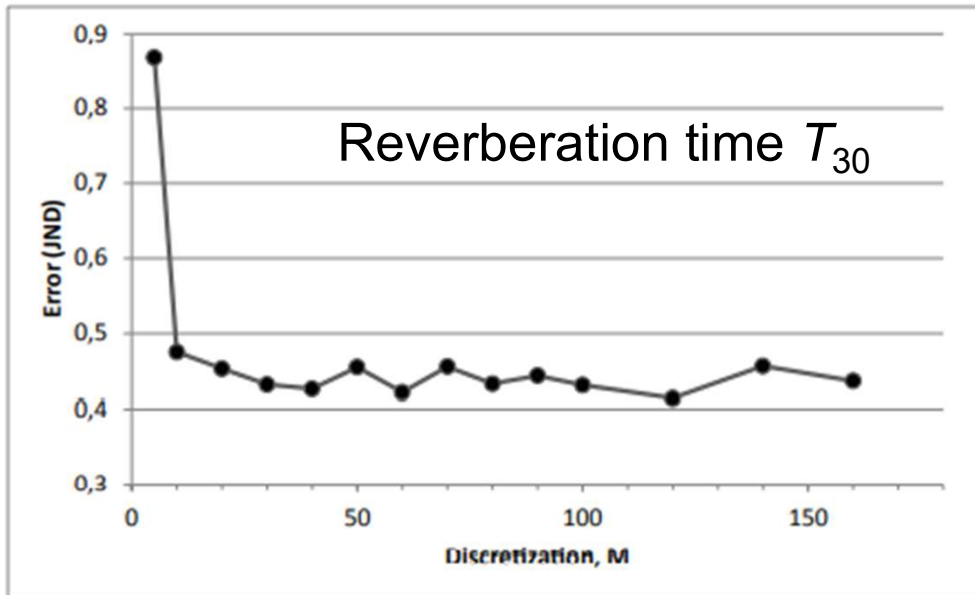


(b) $(M, N) = (100, 23)$.

M = Number of sections in the main dome

N = Number of sections in the half domes and arches

Global error as function of M

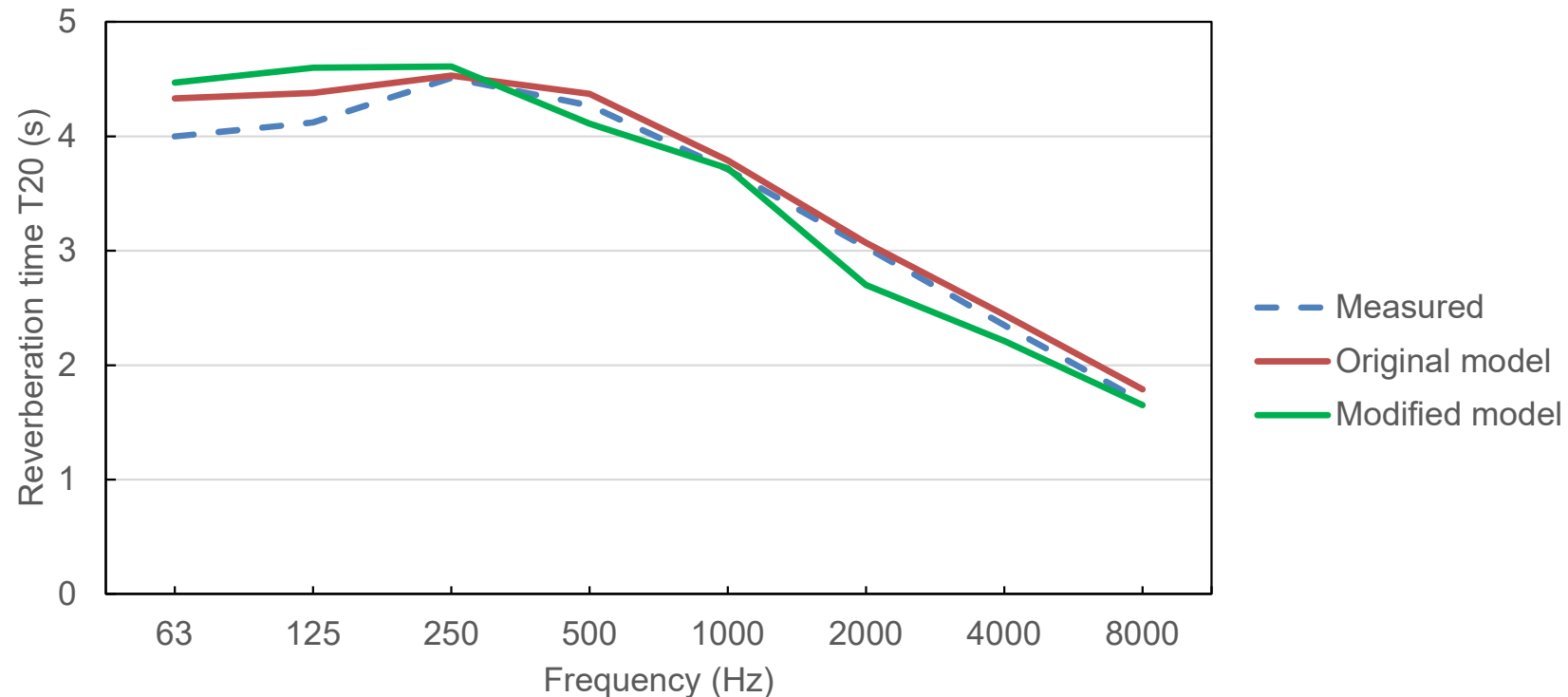


Global error: Difference between measured and simulated results
Averaged over positions (30), and frequencies (8 octaves)

It is sufficient that $M \geq 50$. Concave surfaces (spheres and cylinders) should be subdivided every 7° . A finer subdivision does not improve the simulations.

Changing the room model

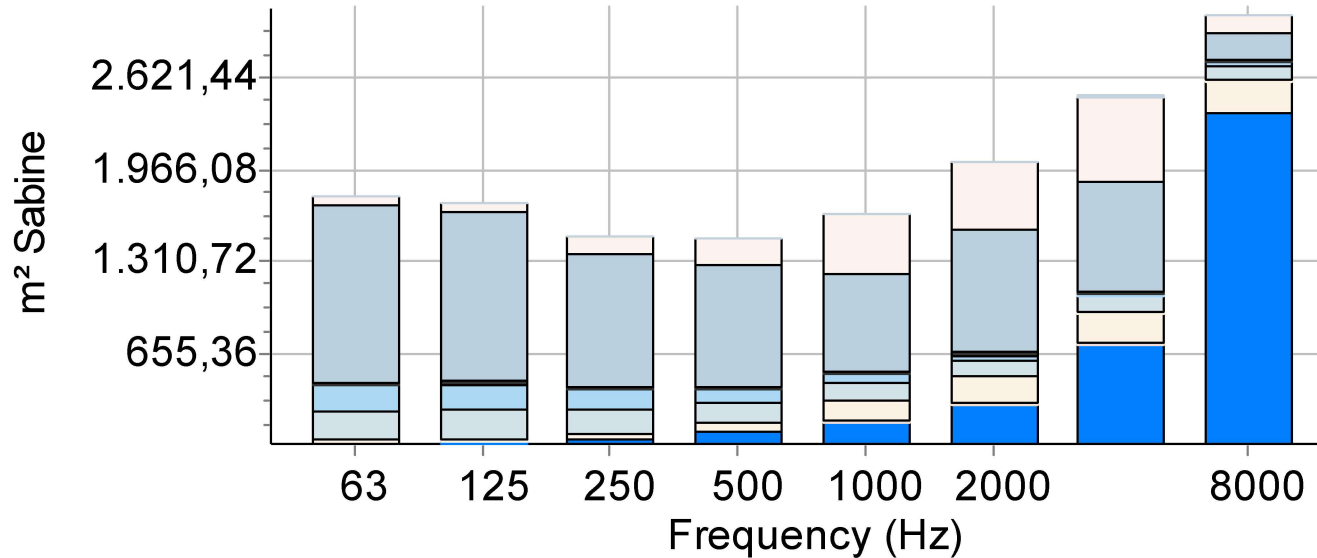
Reverberation time averaged over positions



Walls changed from porous brick to plaster
Floor changed to represent a crowd of people

Absorption areas per material

Absorption area distributed on materials

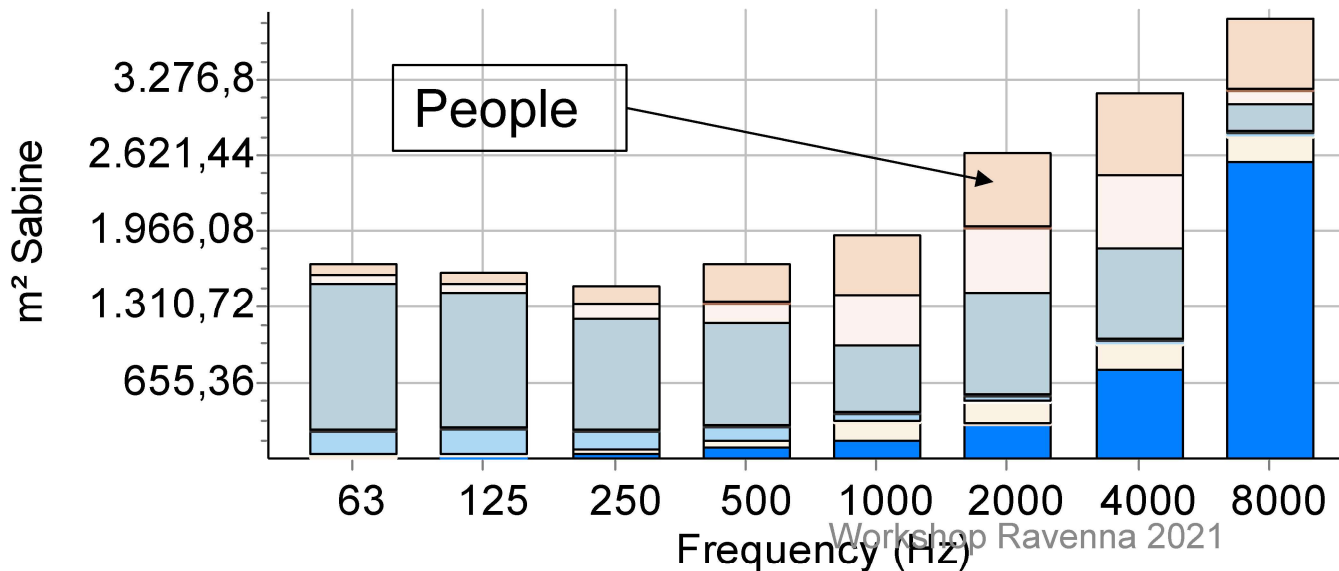


Original



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Absorption area distributed on materials



Modified



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Anothen hoi prophetai

A song in honour of Mary, Mother of God (*Theotokion*) 'The Prophets from Heaven', sung in mode 'Barys' ('Low mode'), also called '3rd plagal mode'. Text and melody are ascribed to the Late-Byzantine singer and composer Ioannes Koukouzeles (14th Century).

It is chanted at the beginning of the service as a tribute to the Theotokos, while the patriarch or metropolitite is being invested with the precious stola, a sign of episcopal dignity.

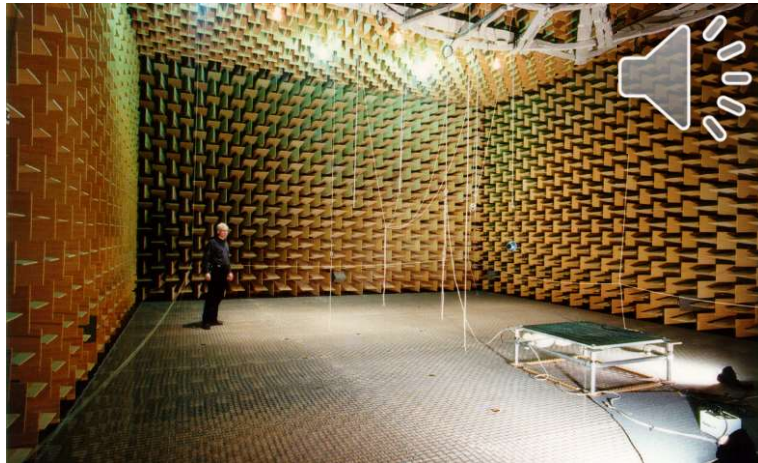
It is here sung by Leonidas Asteris (born 1936, first cantor of the Great Church of the Ecumenical Patriarchate in Istanbul/Constantinople).

Recorded 2001 as part of the CAHRISMA project.

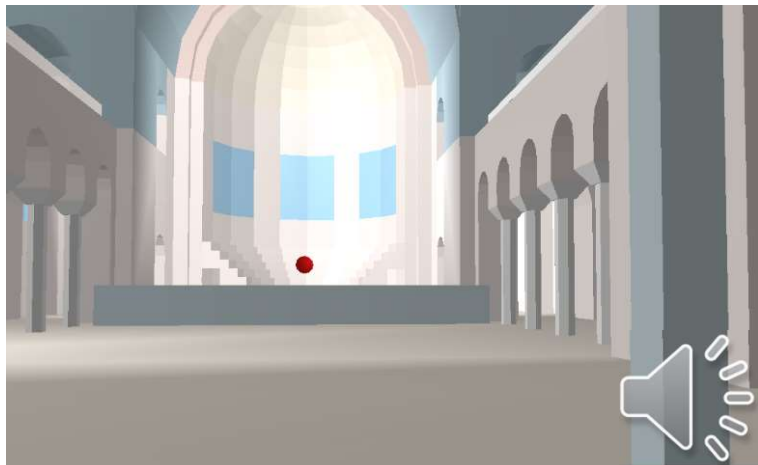


Auralisation technique

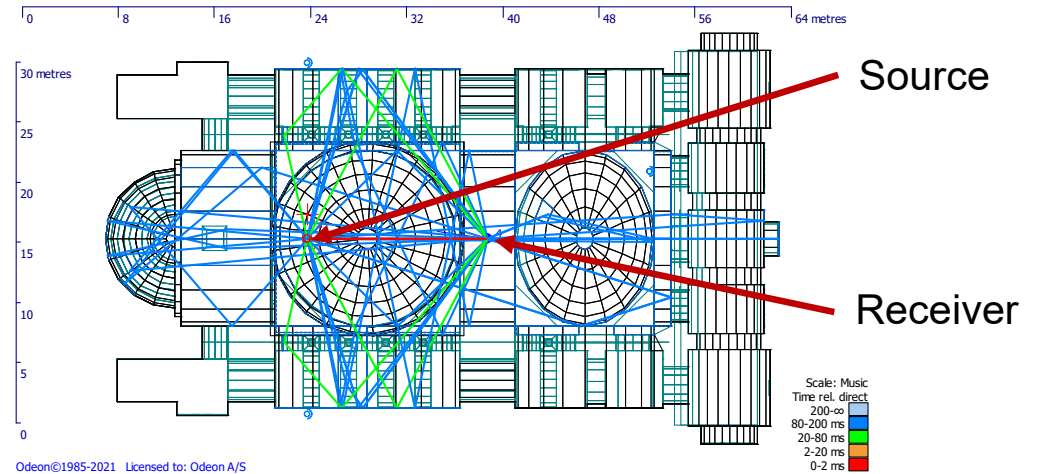
The anechoic input



21 s

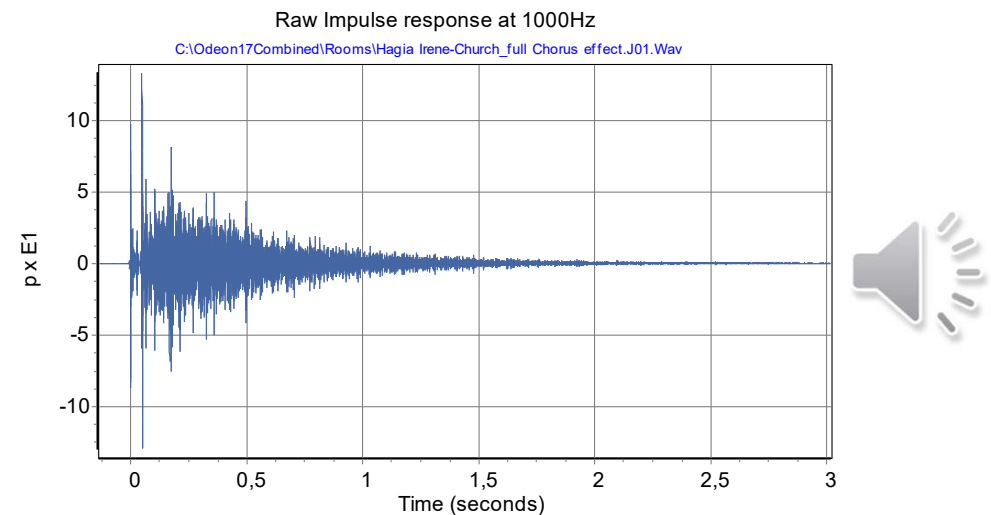


The convolved result



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The Room Impulse Response



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Alleluia

Byzantine *Alleluia* with verse, ‘O come, let us rejoice in the Lord’ (Ps. 95.1) in 4th plagal mode.

Sung in *Hagia Sophia* first Sunday after Easter (*‘Antipascha’*) according to the *Typikon of the Great Church*, dating back to around 950, which is the oldest document with precise information on the cathedral liturgy in Hagia Sophia.

The music is transcribed from two manuscripts from the Vatican Library (Biblioteca Apostolica Vaticana), namely Vat. gr. 1606 (intro + refrain), and Vat. gr. 345 (verse).

The transcription is made by Christian Troelsgård

Alleluia

Intonation (soloist): Νεάγιε. [*Intonation melodi ('martyria') of the 4th plagal mode*]

Intro (soloist): Ἀλληλούϊα. Ψαλμὸς τῷ Δαυίδ. [*A Psalm by David*]

Refrain (choir): Ἀλληλούϊα, ἄλληλούϊα, ἄλληλούϊα. [*Halleluja, halleluja, halleluja*]

Verse (soloist): Δεῦτε ἀγαλλιασώμεθα τῷ κυρίῳ, [*O come, let us rejoice in the Lord*],
ἀλαλάξωμεν τῷ θεῷ τῷ σωτῆρι ἡμῶν. [*Let us make a joyful noise to God, our Saviour*]

Refrain (choir): Ἀλληλούϊα, ἄλληλούϊα, ἄλληλούϊα. [*Halleluja, halleluja, halleluja*]



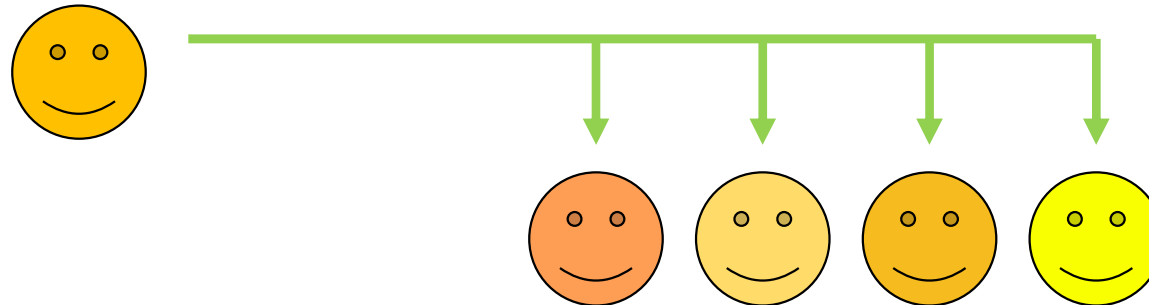
Anechoic recording at DTU,
17 December 2009.

Performed by Christian
Troelsgård and Thomas
Troelsgård.

Choir virtually generated by
ODEON.

The chorus effect

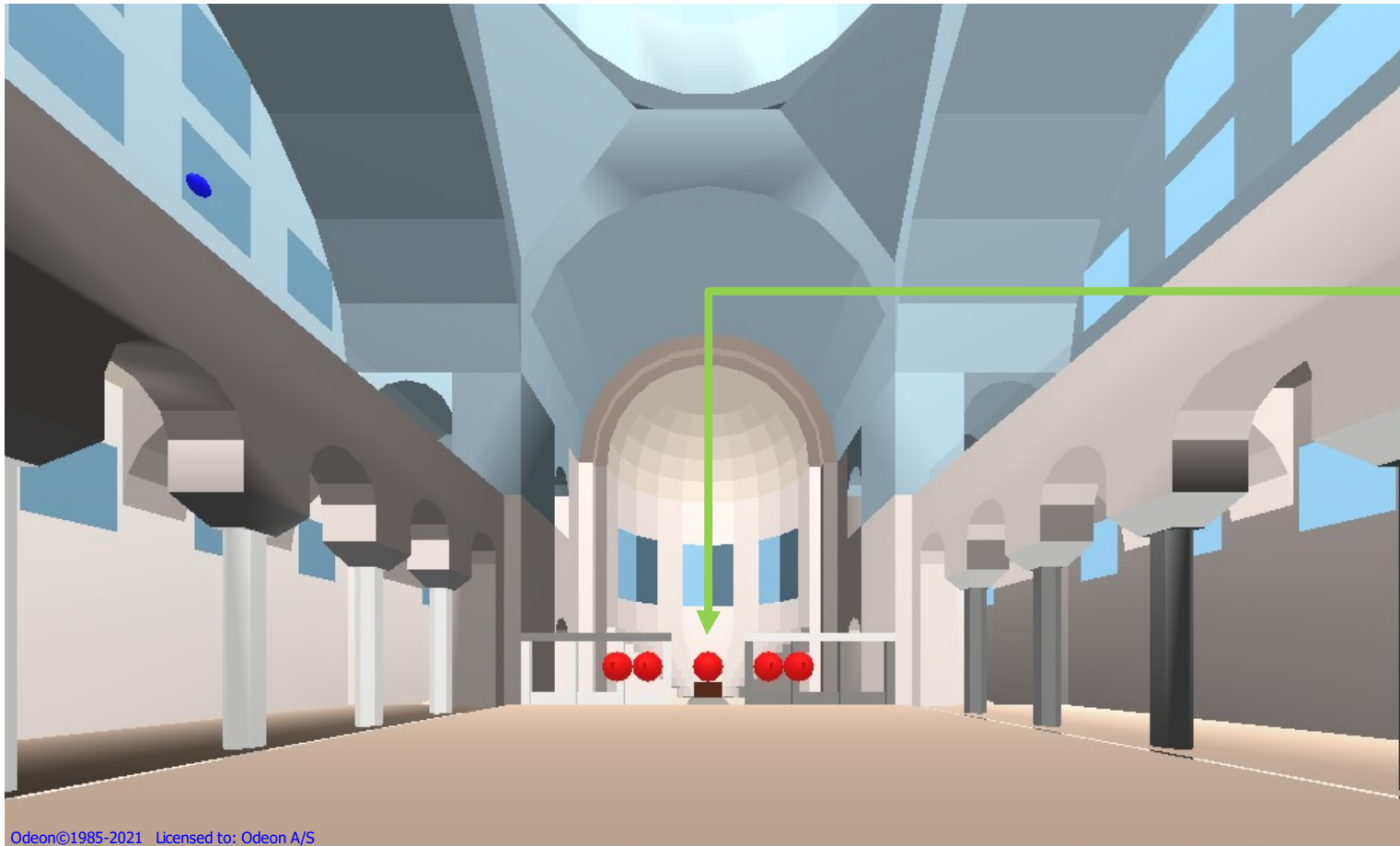
- The ODEON Audio Fx tool
- Based on the recording of a single voice
- Automatic creation of a number of nearly similar copies, but none perfectly identical



Link: [odeon.dk/learn/video-tutorials/conference-presentations/Audio effects for multi-source auralisations \(I3DA 2021\)](https://odeon.dk/learn/video-tutorials/conference-presentations/Audio%20effects%20for%20multi-source%20auralisations%20(I3DA%202021))

Ref.: Proceedings of I3DA, International Conference on Immersive and 3D Audio 8-10 September 2021, Bologna, Italy. Paper N068.

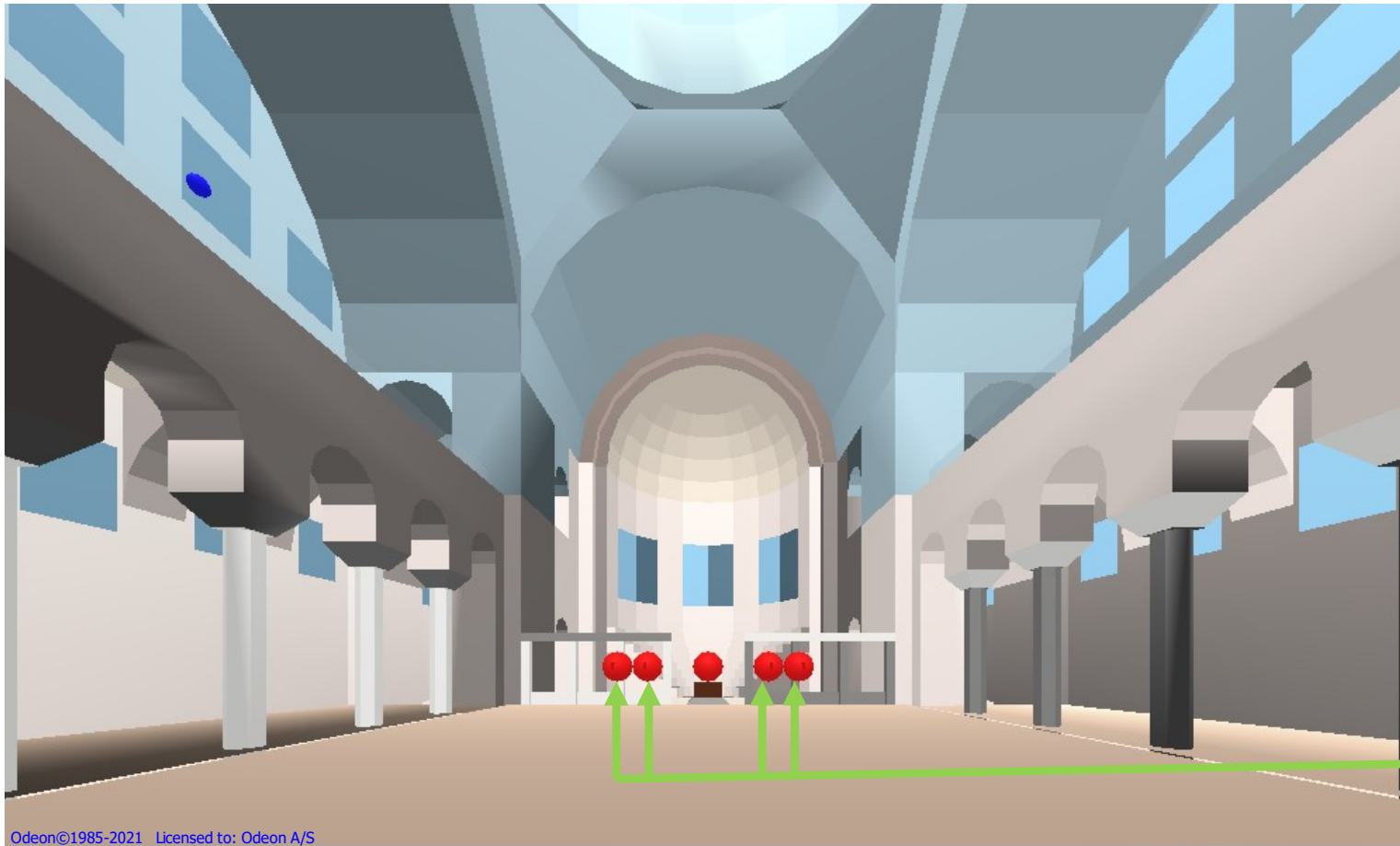
Alleluia in St Irene



Cantor (solo)



Alleluia in St Irene



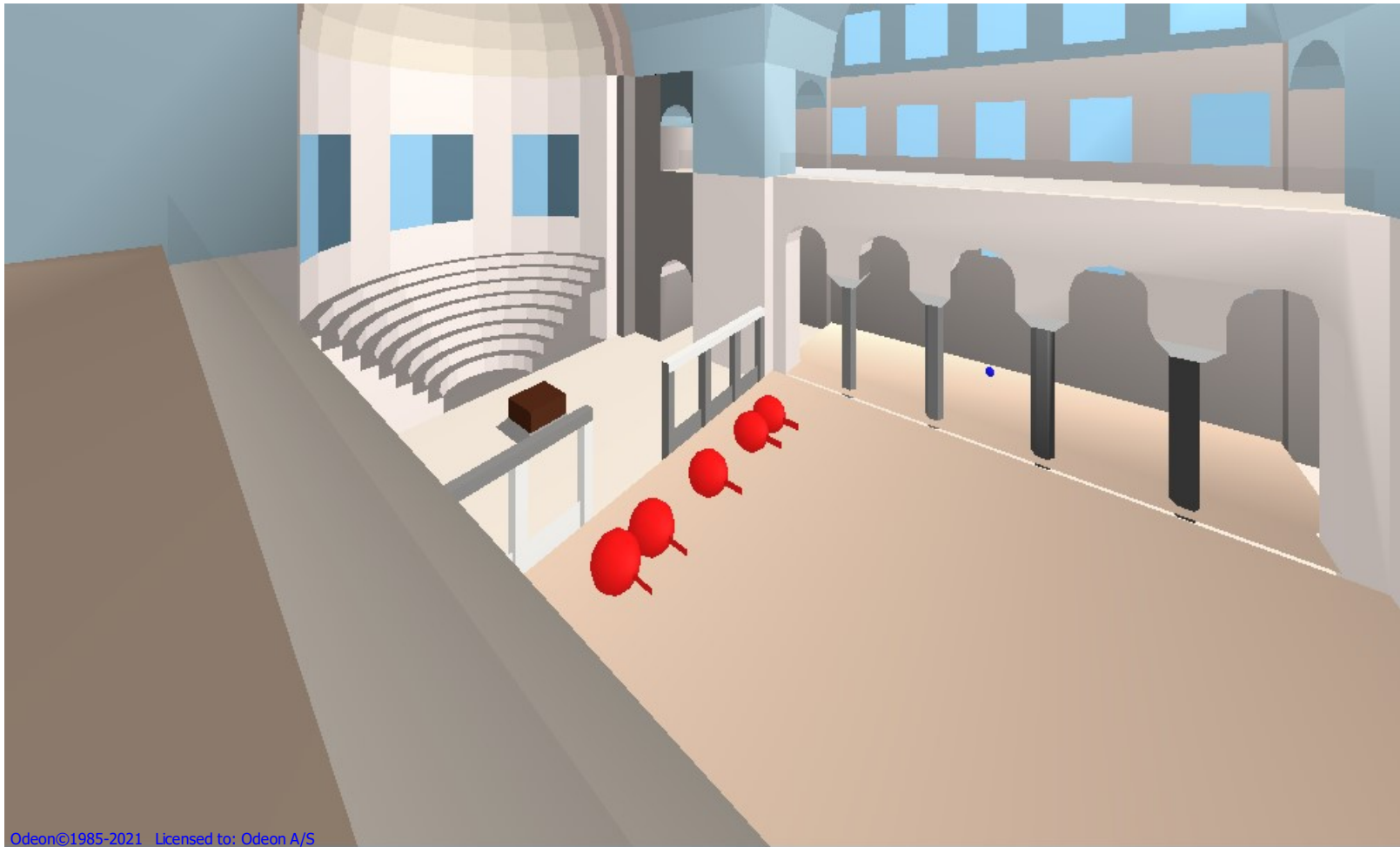
Refrain (choir)

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Alleluia in St Irene

Position on balcony



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3 m 48 s



Cultural heritage and room acoustics

- Measurements are important as reference for material properties
- Geometry of acoustic room model does not need very high degree of detail
- Anechoic recordings may be used for auralisation of the virtually reconstructed room
- A recently developed technique is available for the ‘chorus-effect’
- Auralisation results can be presented through headphones or loudspeakers – this must be specified