

4aMU7: Preliminary report on the effect of room acoustics on choral performance in Notre-Dame and its pre-Gothic predecessor

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Project Context www.pasthasears.eu

- Part of the project PHEND: The Past Has Ears at Notre-Dame.
- Interdisciplinary project with partners in musicology, history, art and architecture history.
- Examines the relationship between the acoustics of the cathedral and the culture surrounding the building during its 850 years of existence.
- Thesis funded by the Acoustics working group of the Chantier Scientific Notre-Dame, in conjunction with the restoration of Notre-Dame de Paris.



NOTRE-DAME DE PARIS 2013-07-24.JPG, PHOTO BY PETER HAAS, CC BY-SA 3.0 VIA WIKIMEDIA COMMONS



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The Musicological Question

Through the first two centuries of its existence, how did the architectural changes effect the composers working in the cathedral?

Did these significant architectural changes influence the development of the style of *Organum Notre-Dame*?

Was it easier to perform *Organum Notre-Dame* in Notre-Dame, compared to the previous cathedral on the site?

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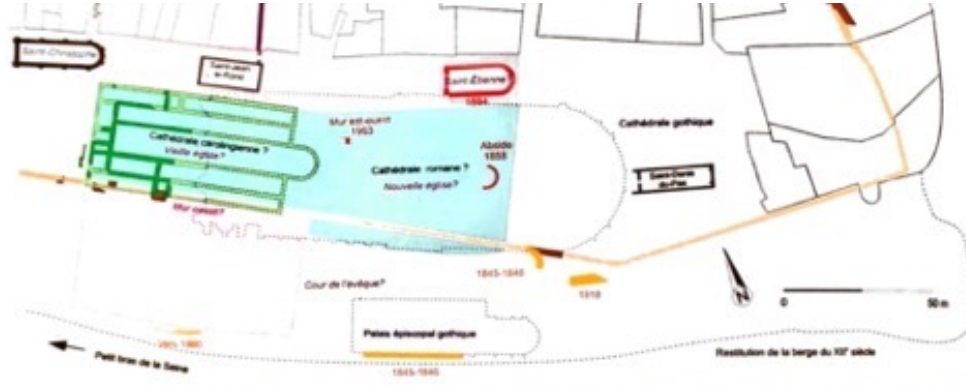
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Methodology

- **Create calibrated, geometrical acoustic models from real measurements of extant buildings [1]**
- **Morph the calibrated models to match the historic states of Notre-Dame de Paris before, during, and after the height of the School of Notre Dame's activity**
- **Create plausible synthetic impulse responses for auralizations**
- **Generate auralizations of historically-informed performances (HIP) for listening tests with expert listeners**
- **Create a system for real-time auralization delivered to HIP specialists for musical adaptation analysis**
- **Extract musical performance parameters related to ease of performance**

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[1] B. N. J. Postma and B. F. G. Katz, 'Perceptive and objective evaluation of calibrated room acoustic simulation auralizations', *JASA*, vol. 140, no. 6, pp. 4326–4337, Dec. 2016, doi:10.1121/1.4971422.



[2] J. BARBIER, D. BUSSON, AND V. SOULAY, 'AVANT LA CATHÉDRALE GOTHIQUE: IVE-XIIIE SIÈCLE', IN *NOTRE DAME DE PARIS*, STRASBOURG: LA NUÉE BLEUE, 2019, PP. 17–27.



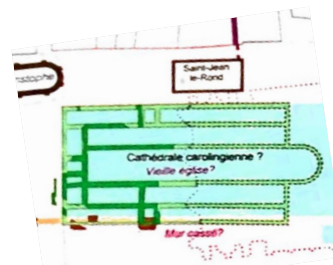
Pre-Gothic Cathedral: 4th Century – 1163 CE

Cathedral:

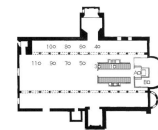
- A Roman basilica style cathedral found under Notre-Dame's parvis
- Believed to have been built in the 4th or 5th centuries
- Geometrical model is based on the Basilica di Santa Sabina all'Aventino in Rome, built in the early 5th century

Music:

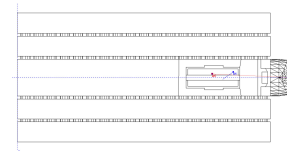
- Functionally heterophonic plainchant



FOOTPRINT OF PRE-GOTHIC CATHEDRAL



FLOORPLAN OF SANTA SABINA [2]



MODEL OF SANTA SABINA MORPHED TO PRE-GOTHIC FLOORPLAN

[3] E. Cirillo and F. Martellotta, 'Sound propagation and energy relations in churches', *JASA*, vol. 118, no. 1, pp. 232–248, Jul. 2005, doi: 10.1121/1.1929231.



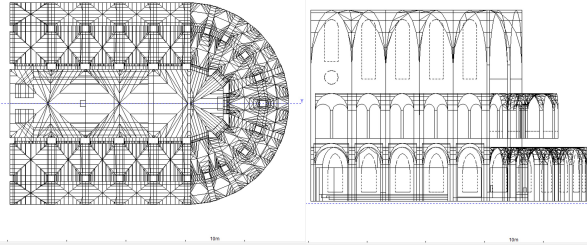
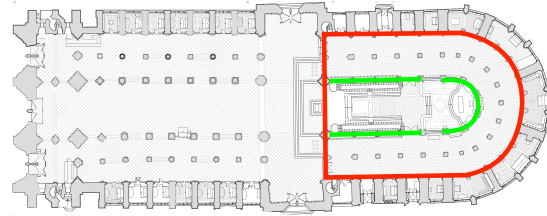
Notre-Dame c.1183-1220

Cathedral:

- Only the apse has been built
- No chapels between the flying buttresses
- Choir and sanctuary are enclosed by clôture (green)
- Wall separating apse from transept crossing

Music:

- Associated with the composer Leonin (established the genre *Organum Notre-Dame*) [3]
- Has a rhythmically complex and harmonically independent upper voice above the tenor voice



[4] C. Wright, *Music and Ceremony at Notre Dame of Paris 500-1550*. Cambridge, UNITED KINGDOM: Cambridge University Press, 1989.

TOP: FLOORPLAN OF C.1182 NOTRE-DAME SUPERIMPOSED ON THE MODERN FLOORPLAN
BOTTOM: GEOMETRIC ACOUSTIC MODEL OF NOTRE-DAME C.1182

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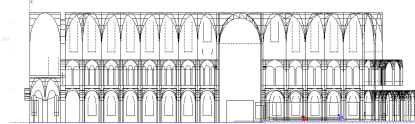
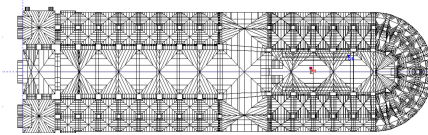
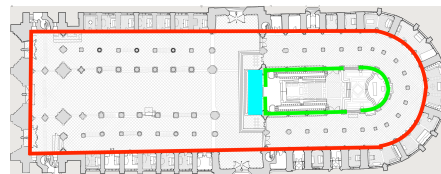
Notre-Dame c.1220-1280

Cathedral:

- Nave and transept completed
- Dividing wall between apse and transept removed

Music:

- Associated with the composer Perotin, Leonin's pupil [3]
- Introduces two more melodically and rhythmically independent voices above the plain chant



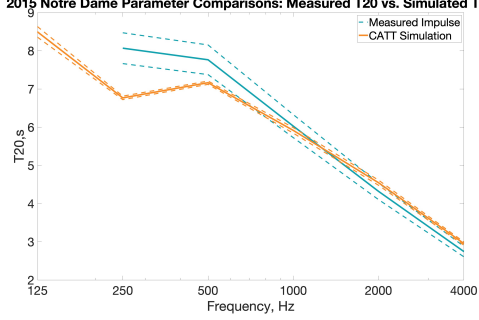
[4] C. Wright, *Music and Ceremony at Notre Dame of Paris 500-1550*. Cambridge, UNITED KINGDOM: Cambridge University Press, 1989.

TOP: FLOORPLAN OF C.1220 NOTRE-DAME SUPERIMPOSED ON THE MODERN FLOORPLAN, WITH JUBÉ AND CLOTURE IN BLUE AND GREEN
MIDDLE AND BOTTOM: GEOMETRICAL MODEL OF NOTRE DAME C. 1220

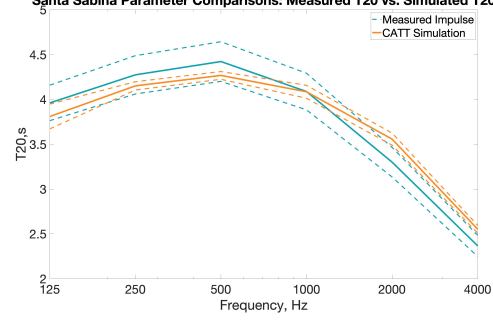
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Demonstration of Calibration:

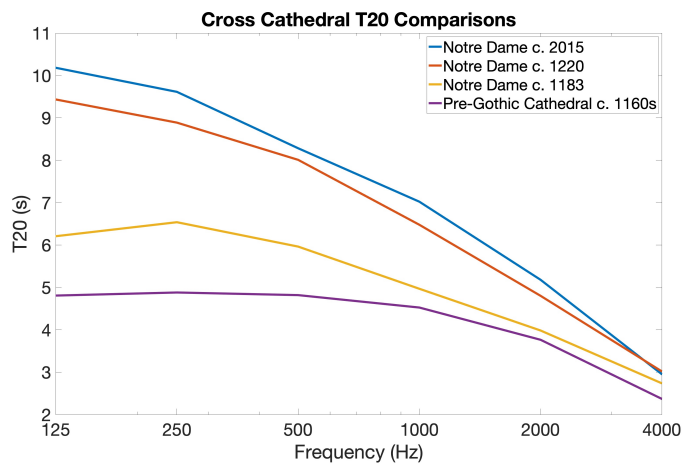
2015 Notre Dame Parameter Comparisons: Measured T20 vs. Simulated T20



Santa Sabina Parameter Comparisons: Measured T20 vs. Simulated T20



Global Acoustic Parameter Comparisons



Cathedral:	C80 _{mid} :
Notre-Dame c. 2015	5.9 dB
Notre-Dame c. 1220	1.1 dB
Notre-Dame c. 1183	2.0 dB
Pre-Gothic Cathedral c. 1163	-1.2 dB



Auralization System Requirements

- Focus of study is performer adaptation inside the virtual acoustic environments
- *Accurate auralization and analysis depend on individual rendering and isolated signals*
- *Adaptation conclusions depend on the system transparency*
- Current tests have focused on microphone selection, ensemble positioning, the presence of acoustic barriers or baffles, and line-of-sight requirements.

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TESTING MICROPHONES FOR CROSS-TALK REJECTION IN THE ANECHOIC CHAMBER



Tests and Technical Difficulties

1: Auralization Validation

- One singer at a time in an acoustically dry room
- Rendering via a 32-channel loudspeaker array or via open-back headphones
- Rendered signal sent to singer and to passive expert listeners nearby

Conclusion: Minor coloration issues detected but plausibility of room response confirmed.

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LEVEL CALIBRATION FOR TEST 1: AURALIZATION VALIDATION



Tests and Technical Difficulties

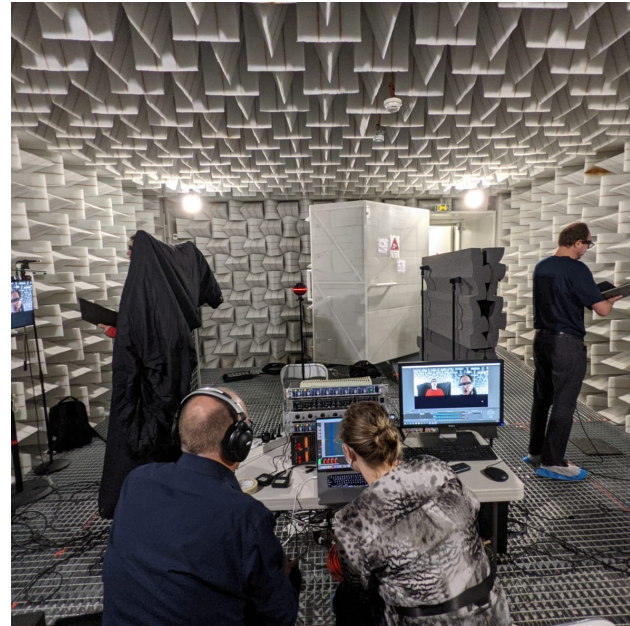
1: Auralization Validation

2: Simultaneous Rendering

- Two singers in anechoic chamber
- Auralization rendered over several models of open-back headphones
- Testing singer position and microphone choice:
 - Back to back with video monitoring
 - Face to face with baffles
 - Face to face without baffles

Conclusion: Face to face with baffles works and open back headphones are not problematic.

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SECOND TEST WITH SINGERS IN WORST-BEHAVING CONFIGURATION.



Tests and Technical Difficulties

1: Auralization Validation

2: Simultaneous Rendering

3: System Expansion

- Four singers in the anechoic chamber
- Auralizations rendered over system selected in step 2
- Testing singer location and orientation for full choir

Conclusion: Positioning and rendering technology that was sufficient for two singers may be unsuitable for the larger ensemble.

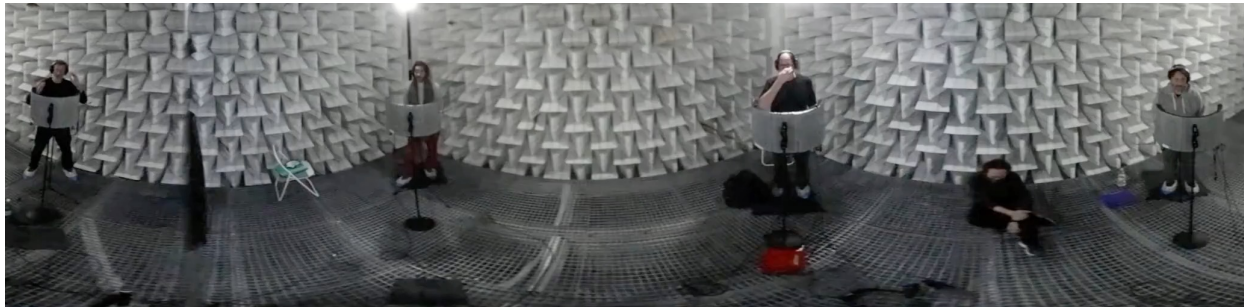
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COLLAPSED CONFIGURATION

Viderunt Omnes (Expanded Configuration)

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Viderunt Omnes (Collapsed Configuration)

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Future Work

- Refine the auralization architecture to be less distracting to the singers
- Conduct listening tests with experts to assess subjective preference related to synthetic room impulses

Special thanks to Prof. Francesco Martellotta for sharing his measurements of Santa Sabina all'Aventino with us.

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Bibliography

- [1] J. Barbier, D. Busson, and V. Soulay, 'Avant la cathédrale gothique: IVe-XIIe siècle', in *Notre Dame de Paris*, Strasbourg: La Nuée Bleue, 2019, pp. 17-27.
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