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Los Angeles

Voice of the Cathedral:

Sound and Space in Twelfth-Century

Notre-Dame of Paris

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Musicology

by

Kacie Morgan

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ABSTRACT OF THE DISSERTATION

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Professor Nina Eidsheim, Co-Chair

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My dissertation project examines the relation between sound and space of twelfth-century polyphony in Notre-Dame cathedral during its construction. Beginning in the second half of the twelfth century, a dramatic shift in rhythmic organization in the polyphonic repertoire at Notre-Dame cathedral occured, moving from Gregorian chant to a highly rhythmic note-to-note texture of discant polyphony. In order to analyze the connection between rhythm and acoustics, my project incorporates methods from sound studies, art history, and the digital humanities with historical musicology. My research enables the reconfiguration of sound as an interactive process between the performing body, the vibration of sound waves, and the physical space that contains the performance. I use digital tools and recent research in art history to reconstruct Notre-Dame cathedral as it might have stood at the end of the twelfth century to

examine the material condition in the changing performance space and to test the acoustics of the space. My re-analysis demonstrates how the material conditions of the cathedral throughout construction directly impacted the sound production and performance within the cathedral, requiring new musical setting and performance practices.

To examine the connection between architecture, acoustics, rhythmic developments, and performance conditions, each chapter examines a new facet of sound and space. In chapter one, I ground a sound-based analysis in the score, and consider the vibrational actualization of notated music to reanalyze polyphonic settings from Wolfenbüttel 1 and the Florence Manuscript. I analyze how rhythmic and textural elements could have functioned as techniques of sound production, the emission of vibrations, and/or sonic emphasis, musical elements designed to highlight, or resound a melodic, harmonic, or rhythmic gesture, in response to the new cathedral acoustics. In chapter two, I investigate the construction history of the cathedral and how the physical and material conditions, including noise and the addition and subtraction of materials, affected performance practice. In chapter three, I analyze the acoustics of the cathedral choir through digital modeling and acoustic simulation, to test elements such as reverberation time, clarity, echo, and sound levels to better understand how the number of singers and the location of singers and listeners affected aural feedback. Finally, in chapter four I analyze the aural feedback of singers and listeners as well as the sonic effects of each polyphonic texture within the acoustics of the choir. All four chapters culminate in this final analysis of how each polyphonic texture sounded to listeners throughout the choir, to provide a new understanding of how the acoustics impacted polyphonic performance.

The dissertation of Kacie Renee Morgan is approved.

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University of California, Los Angeles

2021

In loving memory of

Ruth Yancey

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Vita

Kacie Morgan is a musicologist specializing in space and sound in the late twelfth century. In her dissertation she combines digital modeling, acoustic simulation, art history, sound studies, and historical musicology. Her research interests also include issues of gender and class in the pastourelle motet, as well as class and whiteness in medieval music. Kacie received a BMA from the University of Oklahoma, graduating *summa cum laude*. She completed a certificate in Digital Humanities from the University of California, Los Angeles (UCLA).

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Laying the Foundation: Origins and Context

On April 15th, 2019 news channels around the world broadcast live footage of the fire blazing on the roof of Notre-Dame cathedral.[1] After 15 hours, the fire was put out and the extent of the damage revealed. The cathedral had lost its roof, spire, some vaults and still Notre-Dame was in jeopardy of collapsing without structural support.[2] Developments in the ensuing days looked bleak as architects and construction workers fought to stabilize the structure and save the cathedral. By April 19th, four days after the fire, the cathedral had been temporarily stabilized (according to some sources) and clean up could begin to prepare the cathedral for repairs.[3] Before the flames had even been extinguished, millions of dollars were pledged by politicians and business moguls alike to renovate the cathedral, wanting to preserve the historical site for various political and cultural reasons.[4] To repair and rebuild the cathedral, the French government, in

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[1] Footage includes: "Scenes from the Notre Dame Cathedral Fire," CNN, New York City, NY: CNN, April 15, 2019. "Notre Dame Cathedral in Paris on fire, live stream," CBS News, New York City, NY: CBS, April 15, 2019. "Notre Dame fire: Paris fire brigade footage shows extent of damage," Global News, Vancouver, BC, April 15, 2019. "What We Know and Don't Know About the Notre-Dame Fire," New York Times, New York City, NY: NY Times, April 15, 2019.

[2] "Notre-Dame fire: Paris surveys aftermath of cathedral blaze," BBC, London, UK: BBC, April 16, 2019. "Notre Dame: Aerial animation shows the damage caused by fire," CNN, New York City, NY: CNN, April 16, 2019. "Fire nearly destroys Notre Dame Cathedral," ABC News, Burbank, CA: ABC, April 16, 2019. "Notre Dame Cathedral devastated by fire in Paris," CBS This Morning, New York City, NY: CBS, April 16, 2019. "Notre Dame Cathedral before and after the devastating fire," Guardian News, London, UK, April 17, 2019.

[3] Nicolas Vaux-Montagny and Sylvie Corbet, AP News, "Fire-ravaged Notre Dame now stabilized, firefighters leave" (April 19, 2019). https://apnews.com/92db19558da04f09b94cc31fb5ce16a5. However, updates from 2020 indicate that the stabilization process continued throughout the year. See: Francesco Bandarin, "Notre Dame enters a new and high risk phase in its restoration: A huge forest of scaffolding, fused by the fire in April, has to be cut away," *The Art Newspaper* (December 30, 2019), https://www.theartnewspaper.com/news/notre-dame-enters-a-new-and-high-risk-phase-in-its-restoration. Natalia Liubchenkova, "In pictures: Inside the restoration project that is bringing Notre-Dame back to life," *Euronews* (April 15, 2020), https://www.euronews.com/2020/04/15/in-pictures-inside-the-restoration-Project-that-is-bringing-notre-dame-back-to-life.

[4] Karie Warren, "Here are all the people and companies who have collectively pledged nearly $730 million so far to help rebuild Notre-Dame after the disastrous fire" (April 16, 2019), *Business Insider.* https://www.businessinsider.com/people-who-pledged-money-to-rebuild-notre-dame-fire-paris-2019-4.

consultation with the heritage conservation organisation Fondation du Patrimoine decided that the cathedral should be rebuilt in a manner identical to what was lost, with the exception of the spire design and, perhaps, roof materials.[5] That is, the restoration will preserve the medieval masonry techniques for stone work and vaulting to preserve the interior of the cathedral.[6] These renovations have begun, but they will be extensive, altering the cathedral forever.

Manon Rescan, "Notre-Dame de Paris: cagnottes, promesses de dons et souscription nationale pour financer la reconstruction," *Le Monde* (April 16, 2019). https://www.lemonde.fr/societe/article/2019/04/16/notre-dame-les-cagnottes-se-multiplient-et-macron-annonce-une-souscription-nationale_5450645_3224.html. Megan Cerullo, "French billionaires slow-walk donations to rebuild Notre Dame," CBS News (July 5, 2019) https://www.cbsnews.com/news/notre-dame-fire-update-big-donors-delay-fulfilling-pledges-to-rebuild-notre-dame/#:~:text=The%20Bettencourt%20Meyers%20family%20and,Schueller%20Foundation%20matched%20the%20pledge. Joel Shannon, "Massive Notre Dame Cathedral donations draw high-profile backlash," (April 19, 2019), USA Today.https://www.usatoday.com/story/news/world/2019/04/18/notre-dame-cathedral-fire-billionaires-donations-spark-backlash/3514968002/ Alice Cuddy and Bruno Boelpaep, "Notre-Dame fire: Has too much money been given to rebuild it?," BBC News (April 25, 2019), https://www.bbc.com/news/world-europe-48039770

[5] Francesco Bandarin, "It's Official: the new Notre Dame will look like the old Notre Dame," *The Art Newspaper* (August 5, 2019), https://www.theartnewspaper.com/analysis/it-s-official-the-new-notre-dame-will-look-like-the-old-notre-dame. Ludovic Marin, "Reconstruction de Notre-Dame: l'avantage aux "petits" donateurs," *Le Monde* (April 17, 2019), https://www.lemonde.fr/politique/article/2019/04/17/incendie-de-notre-dame-lancement-d-un-concours-international-d-architectes-pour-la-fleche_5451615_823448.html. Eileen Kinsella, "France Approves a Reconstruction Plan for Notre Dame. But Some Say It's Moving Too Fast, Risking Further Collapse," *Artnet News* (July 17, 2019). https://news.artnet.com/art-world/france-reconstruction-notre-dame-1603318. Jake Cigainero, "What Will a Reconstructed Notre Dame Look Like? The Answer is Up For Debate," *NPR* (September 5, 2019), https://www.npr.org/2019/09/05/757472597/what-will-a-reconstructed-notre-dame-look-like-the-answer-is-up-for-debate. Liam James, "Notre Dame design competition seeks new roof for world famous Paris cathedral," *Independent* (June 21, 2019). https://www.independent.co.uk/news/world/europe/notre-dame-cathedral-roof-fire-design-competition-paris-france-a8968791.html. Matt Hickman, "Restoration work resumes at Notre Dame but spire replacement plans remain at a standstill," *The Architect's Newspaper* (May 8, 2020), https://archpaper.com/2020/05/restoration-work-resuming-notre-dame-spire-plans-halted/. See also: Christa Lesté-Lasserre, "Scientists are leading Notre Dame's restoration—and probing mysteries laid bare by its devastating fire," *Science Magazine* (March 12, 2020), https://www.sciencemag.org/news/2020/03/scientists-are-leading-notre-dame-s-restoration-and-probing-mysteries-laid-bare-its.

[6] The news on this matter continues to be unclear and contradicting as progress continues, however sources indicate that the cathedral will be rebuilt as identically to what stood before as possible. See footnotes 4 & 5.

In the wake of the fire, musicologists mourned the loss of their “connection” to the medieval performance space.[7] Simultaneously, they acknowledged that the medieval space had already been lost for years.[8] The cathedral that came close to falling was a different version than the one that the lauded medieval composers had stood within. medieval scholars’ intimate material connection to the past was lost. Scholars viewed replacing the lost vaults as such a fundamental change that the acoustics of the cathedral would never be quite the same. As such, all scholars now have to face the hard truth that we can no longer pretend to share an acoustic space with those historical figures whose repertoires they performed. Scholars acknowledge just how pivotal changes in materials and performance spaces are to music, even if that’s not the intention of their interview statements.

The role of space and acoustics in musical performance practice has long been acknowledged by opera and symphonic music scholars. The development of opera halls and concert halls has been examined by architectural acousticians, musicians, and musicologists alike. The experiential and sonic interventions in halls like Bayreuth, Grosser Musikvereinssaal in Vienna, the addition of balconies, omitting boxes in opera

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[7] Media coverage sought out scholars who could explain the architectural, musical, and liturgical significance of the cathedral to emphasize the loss of history that was occuring. See: Margot Fassler, “Margot Fassler speaks about France’s Notre Dame Cathedral in response to recent fire” *Sacred Music Notre Dame* (April 16, 2019), Michael Scott Cuthbert “Op-Ed: Notre Dame can be rebuilt but its unique sound may be gone forever,” *Los Angeles Times* (April 16, 2019). Jennifer Hambrick, “Notre Dame Cathedral: The Birthplace Of Music As We Know It Today,” *WOSU Radio* (April 16, 2019). Hannah Silverstein and Nicola Camerlenghi, “After the Fire, a 21st-Century Notre Dame” *Dartmouth News* (April 20, 2019), https://news.dartmouth.edu/news/2019/04/after-fire-21st-century-notre-dame. Additionally, academic journals requested comments and commissioned collected responses to the fire to further highlight the complex history of the cathedral and its practices. See: “Meditations after the Fire: Scholars on Notre Dame,” *Post Medieval* 10 (2019), 513-526. Jacek Blaszkiewicz, “Three Musical Works About “Old Paris,”” *Musicology Now* (Thursday, May 2, 2019). See also: Emily Conover, “How to restore the legendary acoustics of Notre Dame,” *Science News* (January 12, 2020), https://www.sciencenews.org/article/notre-dame-cathedral-fire-legendary-acoustics-restoration.

[8] Fassler, “Margot Fassler speaks.” Cuthbert, “Op-Ed: Notre Dame.” Hambrick, “Notre Dame Cathedral.”

halls, the increase in the size of the halls, and the codification of the concert-going experience all factors considered within the history of music performed in halls dedicated to house a specific repertoire.[9] The history of concert halls adminetly connects, even by acousticians such as Leo Beranek, to the growth and development of the symphony orchestra. The growth of the size and sounds within the symphony orchestra necessitated larger, more robust performance spaces to house the orchestras.[10] The history of opera halls relates the change of subject, performance style, and opera-going experience to the change in the layout and design of the opera hall. The opera hall and concert hall were both changed as the music became the center focus of events and the stage became the sole focus of the seating arrangement. The acoustic characteristics that defined a "good" hall was defined and honed further with the rise of acoustics and the ability to tune the space to the sounds it would house.

Musicologist's primary understanding of the sounds and response within opera and concert halls comes to musicologists as a result of the rise of the science of acoustics. Though understanding and experiments with acoustics began as early as antiquity, acoustics as a principle to design and measure sound did not begin until the nineteenth century.[11] Acoustics provides an understanding of how to control sound, and,

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[9] Massimo Garai, Ken Ito, et al., "The Acoustics of Bayreuth Festspielhaus," presented at The 22nd International Congress on Sound and Vibration, Florence 2015. Michael Forsyth, *Buildings for Music: the Architect, the Musicians, and the Listener from the Seventeenth Century to Present Day* (Cambridge: MIT Press, 1985), 163-233. On opera houses, balconies and listening see: Victoria Newhouse, *Site and Sound: The Architecture and Acoustics of New Opera Houses and Concert Halls* (New York: The Monacelli Press, 2012).

[10] Forsyth, *Buildings for Music*. Leo Beranek, *Concert halls and Opera houses: music, acoustics, and architecture* 2nd ed. (New York: Springer, 2004).

[11] On acoustics and hearing from antiquity to the early modern period see: Mark M. Smith, ed., *Hearing History: A Reader* (Athens: The University of Georgia Press, 2004). Charles Burnett, Michael Fend, and Penelope Gouk, eds. *The Second Sense: Studies in Hearing and Musical Judgement from Antiquity to the Seventeenth Century* (London: The Warburg Institute University of London, 1991). Dorothea

beginning in the twentieth century in particular, played a pivotal part in the development of opera and concert halls. Acousticians in the late nineteenth and early twentieth century began to define specific sound qualities—such as reverb, clarity, and intimacy—that well-liked concert halls already possessed, and learned how to replicate them.[12] Architectural acousticians of the early to mid-twentieth century worked to find formulas for creating idealized acoustics in different shaped and sized halls, aiming to increase audience size without losing the sound quality of smaller halls. The placement, amount, and type of materials, as they would discover, mattered just as much as the shape and size to create a performance space that suited the needs of the listener and performer. By the mid-twentieth century, architectural acousticians had formulae and numerical values to evaluate acoustic qualities, and extensive technology with which to test and create performance halls. As such, opera and concert halls and the sound and acoustic technologies within them have become the foundation and rubric from which to judge the acoustic features, sound quality, and ideal listening characteristics of other performance spaces.

Despite acousticians' and musicologists' acoustic knowledge—including acoustic tools, opera and concert hall design, and instruments—our relationship to historical performance spaces is tenuous at best. Acoustics have primarily been studied in order to design new acoustic spaces or to preserve specific acoustics seen in large studies of concert halls or performance halls (such as those of Leo Beranek, Michael Forsyth, and

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Baumann and Barbara Haggh, "Musical Acoustics in the Middle Ages" *Early Music* 18, no. 2 (May, 1990), 199-210. Architectural treatises including Vitruvius and others.

[12] Emily Thompson, *Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900-1933* (Cambrdige: MIT Press, 2002).

Michael Hammond).[13] Acousticians who have studied historical spaces do not always attempt to understand the acoustic qualities through the time period in which they were constructed and instead disparaged spaces not built for sound in the same manner as later acoustic designs. For instance, in *Spaces Speak, Are you Listening?* Barry Blesser and Linda-Ruth Salter discuss the acoustics of Gothic cathedrals as a way to reconnect to the caves of their ancestors, disparaging the long reverb time as negative and an accidental quality.[14] The acoustic testing of cathedrals and churches has primarily been conducted for renovations, for the preservation of the acoustic space itself, or intrigue into specific acoustic phenomena. For instance, two acoustic studies of Notre-Dame of Paris (1987 and 2015) were conducted to preserve the acoustics of the cathedral, the acoustics of St. Pauls in London were tested to gather information on the whisper gallery within the cathedral.[15] Only more recently has acoustic testing served as a method of historical investigation, as will be discussed below. Because the understanding of historical acoustics outside of the concert and opera halls are minimal, musicological understanding of the acoustics of large Gothic cathedrals is limited.

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[13] Beranek, *Concert halls and Opera houses*. Forsyth, *Buildings for Music*. Michael Hammond, *Performing Architecture: Opera Houses, Theatres and Concert halls for the twenty-first century* (London: Merrell Publishers, 2006).

[14] Barry Blesser and Linda-Ruth Salter, *Spaces Speak, are you listening?: experiencing aural architecture* (Cambridge: MIT Press, 2007), 88-90.

[15] B.N.J. Postma and B.F.G. Katz, "Acoustics of Notre-Dame cathedral de Paris" Presented at The 22nd International Congress on Acoustics, (Buenos Aires, September 5-9, 2016). John Anderson and Torben Jacobsen, "RASTI Measurements in St. Paul's Cathedral in London" *Bruel & Kjaer, Application Note, BO (1985): 116-121.* Numerous studies can be found about RASTI (rapid speech transmission index) measurements in churches and cathedrals, as apparently acoustics are interested in speech clarity within religious spaces. See also: Antonio P Carvalho, "Relations between rapid speech transmission index (RASTI) and other acoustical and architectural measures in churches" *Applied Acoustics* 58, no 1 (1999), 33-49. J.S. Anderson and M. Bratos-Anderson, "Acoustic coupling effects in St. Pauls' cathedral, London" *Journal of Sound and Vibration* 236, no. 2 (2000), 209-225. Ettore Cirillo and Francesco Martellota, "Acoustics of Apulian-Romanesque churches: an experimental survey" *Building Acoustics* 9, no. 4 (2002), 271-288. Though, note by the dates of these articles that the investigation of the acoustic features of churches in gaining popularity in the 2000s.

Musicologists also seem to have a tumultuous relationship to cathedral and churches as performance spaces. Many, including Graham, discussing Ockeghem's prolation mass, or Charles Warren and Craig Wright's analysis of Guillaume Dufay's *Nuper Rosarum Flores* acknowledge that music is often composed and performed within these spaces, but analyze the relationship only between architectural features and written music structures, refraining from discussing performance.[16] Others, such as Fassler, and Anne Walters-Robertson examine the rites and rituals of a space without connecting the musical practices to how the edifice changed, the cathedral's materials, or providing any notions that the cathedral did more than house the practices.[17] Some scholars, including Craig Wright on Notre-Dame, make the occasional passing statement on the matter of how the space affected sound, but choose not to engage further.[18] As such, scholars fail to discuss how performances engaged with or adapted to the medieval singers' surroundings. There are, of course, notable exceptions. For instance, the importance of the church or cathedral space has always been a central focus of the work of Vasco Zara. Zara's studies examine religious theology, music

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[16] Charles W. Warren, "Brunelleschi's Dome and Dufay's Motet," The Musical Quarterly 59 (1973): 92–105. Craig Wright, "Dufay's Nuper rosarum flores, King Solomon's Temple, and the Veneration of the Virgin," Journal of the American Musicological Society 47, no. 3 (1994): 395–441. For a new analysis of space and music of *Nuper Rosarum Flores,* see Emily Zazulia, "Out of Proportion: *Nuper rosarum flores* and the Danger of False Exceptionalism" *The Journal of Musicology* 36, no. 2 (2019): 131-166.

[17] Anne Walters-Robertson, *The Service-Book of the Royal Abbey of Saint-Denis: Images of Ritual and Music in the Middle Ages* (Oxford: Clarendon Press, 1991). Anne Walters, "The Reconstruction of the Abbey Church at St-Denis (1231-81): The Interplay of Music and Ceremony with Architecture and Politics," *Early Music History* 5 (1985), 187-238. Margot E. Fassler, *The Virgin of Chartres: Music History through Liturgy and the Arts* (New Haven: Yale University Press, 2010). In this book, Fassler does address the sculpture, iconography, and the construction of churches and renovations of the cathedral after a fire in 1134 but does discuss it beyond the liturgical and political figures involved and the atmosphere of piety in Chartres after the fire.

[18] Craig Wright, *Music and Ceremony at Notre-Dame of Paris, 500-1500* (Cambridge: Cambridge University Press, 1989), 17-18. In this discussion, Wright addresses the increased uses of draperies and cloths to help deaden the space for more florid polyphony in the 15th century in particular.

theory, and architecture to re-examine the designs of, and relationships between space, performance, and music.[19] In "Music of Forty Several Parts," Ian Woodfield re-analyzed Spem in Alium by Thomas Tallis, hypothesizing its creation for performance within Nonsuch Palace inspired the compositional design of the choirs, so that the entrances of each new singer would gradually enclose the audience in surround sound from the eight choirs.[20] Finally, Emma Dillon also explores the location and soundscapes surrounding the motet to reinvestigate how scribes and composers experimented with capturing the soundscapes around them in musical form. Studies such as these by Zara, Woodfield, and Dillon indicate that much can be learned from examining the music within its performance space.

Currently, it is the art historians that are most interested in the practical uses and experience of early performance spaces. Architectural historians in particular have examined the functionality and way that a church or cathedral visually and physically captures and reflects the practices within using primary sources, acoustics, and analysis of liturgical practices and historical context. In investigating the history of churches and cathedrals, art and architectural historians such as Sharon Gerstel, Deborah Howard, Laura Moretti, Bissera Pentcheva, and John N. Wall have begun to analyze evidence of music and liturgical practices present within the spaces themselves. For instance, Byzantine churches that have paintings of chants in specific locations in the churches

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[19] Vasco Zara, "Music, Architecture, Proportion and the Renaissance Way of Thinking," *European Review* (2020): 1-16. Vasco Zara, "Musique et Architecture: théories, composition, théologie (XIIIe-XVIIe siècles)," *Bulletin du centre d'études médiévales d'Auxerre* 11 (2007). https://journals.openedition.org/cem/1178. Jean-Christophe Valiere, Benedicte Bertholon-Palazzo, Pauline Carvalho, Estele Dupuy, David Fiala, and Vasco Zara "The Contribution of Human Sciences to the Interpretation of the Use of Acoustic Pots in France and in Bordering Countries from the 12th to the 17th Century," *The Journal of the Acoustical Society of America"* 141, no. 5 (2017): 37-74.

[20] Ian Woodfield, "Music of Forty Several Parts: A Song for the Creation of Princes," *Performance Practice Review* 7, no 1 (Spring, 1994), 54-64.

(Gerstel), Renaissance churches added new choir lofts, and/or pulpits and rearranged the seating arrangement of the chapter and wealthy donors (Howard), and in churches both Byzantine and Christian alike, the aesthetics and ambiance of churches and cathedrals affected the response of worshippers (Pentcheva). Additionally, other projects work to recreate and explore the experience of different historical soundscapes, including the Virtual St Paul's Cathedral Project (Wall) and Myléne Pardoen's sonic reconstruction of Paris' Grand Châtelet to further understand the spaces and happenings at or within them. Each of these projects are concerned with the live, sensorial practices and sounds at their respective location. They use written or painted evidence to examine sounds and bodies within the church, cathedral, or city. With scholars producing studies such as this, as musicologists we must ask ourselves: why are we not more willing to relate the dizzying amounts of information about musical practices, personnel, and rhythmic and melodic development to their physical surroundings? Are we really trying to say that only written innovations drove musical development? But how could sound not matter to medieval musical production and creation?

In this dissertation I explore the relationship between sound, acoustics, singing, and the cathedral of Notre-Dame of Paris at the end of the twelfth and into the beginning of the thirteenth century. To date, musicologists have not been unaware that the cathedral was under construction during the period that is thought to have featured great rhythmic development (1150-1250). However, none have considered how the changing materials and acoustic characteristics affected and influenced musical and rhythmic development through construction. In this study, I primarily investigate the period between 1163-1208, the period that includes the works attributed to Léonin, the *quadrupla* of Pérotin, and the completion of the choir of the new cathedral. I combine historical musicology with sound studies, acoustics, and art history to analyze musical, architectural, and acoustic features not previously considered in discussions of the development of Notre-Dame polyphony. I use sound studies and acoustics to provide new insights into sonic actualization and performance conditions within the cathedral not recorded in sources. In this study, I put the materials of the cathedral and the bodies of the singers and listeners at the center of my examination in order to consider how each acoustic feature and alteration to the choir due to construction impacted singing and aural feedback within the choir of Notre-Dame.

Sound, Music, and the Medieval

It must be acknowledged that musicological conceptions of "sound" and "music" also lie at the core of understanding musical developments in relation to space. Through the history of musicology, music is equated or reduced to the musical score—the stagnant, written object that is our link to the composer and that can be studied without accounting for change.[21] Many factors have contributed to the codification of the score as music, but none as much as the development of the composer, the concept music as "art for art's sake," the "Work concept," and the development of concert culture during

[21] Christopher Small, *Musicking: The Meanings of Performing and Listening* (Hanover: Wesleyan University Press, 1998). Nina Eidsheim, *Sensing Sound: Singing and Listening as Vibrational Practice* (Durham: Duke University Press, 2015). Carolyn Abbate, "Music—Drastic Or Gnostic?," *Critical Inquiry* 30, no. 3 (2004), 505-536. Angeles Sancho-Velazquez, *The Legacy of Genius: Improvisation, Romantic Imagination, and the Western Musical Canon* PhD diss. (Los Angeles: University of California Los Angeles, 2001).

the Romantic period.[22] During the Romantic period, composers were able to rise to prominence, celebrated not only as "great men" but also celebrated, in many cases, by both wealthy patrons and the general public as seen in cases such as Ludwig Van Beethoven, Richard Wagner, and Franz Liszt.[23] Romantic notions of the musical work and greatness of the composer have been upheld by musicologists in many avenues seen prominently in subfields including sketch studies and reception studies.[24] The importance of the score and the codification of the score as music has additionally been furthered by musicology's reliance on composers and music theory to discuss musical features within the score. Most infamous is Heinrich Schenker's *The Art of Performance* in which he argues that a composition does not need a performance to be a masterwork, and that if not properly informed, the performance does injustice to the music.[25] The concept of the composer and music as art born from the Romantic era in

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[22] Eduard Hanslick, *The Beautiful in Music: A Contribution to the Revisal of Musical Aesthetics, trans.* Gustav Cohen, (London: Novello, Ewer and Co., 1891). Carl Dalhaus, *Foundations of Music History, trans* J. B. Robinson (Cambridge: Cambridge University Press, 1983). Ruth Katz and Carl Dahlhaus, *Contemplating Music: Source Readings in the Aesthetics of Music* (Stuyvesant: Pendragon Press, 1987). Lawrence Kramer, *Musical Meaning: Toward a Critical History* (Berkeley: University of California Press, 2002). Lydia Goehr, *The Imaginary Museum of Musical Works: An Essay in the Philosophy of Music* (Oxford: Clarendon Press, 1992).

[23] On "great men," see Thomas Carlyle, *On Heroes, Hero-Worship and the Heroic in History* (London: Chapman and Hall, 1840). On Beethoven: Scott Burnham, *Beethoven Hero* (Princeton: Princeton University Press, 1995). On Wagner: Barry Millington, ed., *The Wagner Compendium: A Guide to Wagner's Life and Music* (London: Thames and Hudson, 1992). Michael Saffle, *Richard Wagner: A Guide to Research* (New York: Routledge Music Bibliographies, 2002). On Liszt: Ben Arnold, ed., *The Liszt Companion* (Westport: Greenwood Press, 2002), 73-178. Alan Walker, *Franz Liszt: The Virtuoso Years 1811-1847 Revised Edition* Vol. 1 (Ithaca: Cornell University Press, 1987). On the expansion of concert halls and their audiences: Newhouse, *Site and Sound*. Michael Forsyth, *Buildings for Music*.

[24] Joseph Kerman, "Sketch Studies," *19th-Century Music* 6, no 2 (autumn, 1982), 174-180. Robert Winter, "Reconstructing Riddles: The Sources for Beethoven's *Missa Solemnis,*" in *Beethoven Essays: Studies in Honor of Elliot Forbes,* ed. Lewis Lockwood and Phyllis Benjamin (Cambridge: Harvard University Press, 1984), 217-250. Klaus Kropfinger, *Wagner and Beethoven: Richard Wagner's Reception of Beethoven*, trans. Peter Palmer (Cambridge: Cambridge University Press, 1974).

[25] Heinrich Schenker *The Art of Performance*, ed. Heribert Esser, trans. Irene Schreier Scott (Oxford: Oxford University Press, 2000).

particular, however, is not the only element contributing to the codification of the score as music.

The codification of the score as music within the discipline of musicology is also a result of many other factors surrounding the development of the score itself and the performance of music. These include factors such as:

Table 0.1: Codification of the score as music

Factor	Product of/impetus	Additional Outcomes
The increased consistency and perceived universality of information communicated via the score	A result of music printing and the gradual inclusion of editorial markings such as articulation, dynamics, and tempi	Increase of score study, reliance on written record, decline of improvisatory practices
Decline of improvisatory practices in Western Classical Music	Change in performance culture in Romantic period, increased editorial and compositional markings within the score	Put even more emphasis on the score, very few schools and instruments retained improvisatory practices (organists and some early music conservatories most notably), change in relationship between memorization and performance.
Changes in musical institutions and musical training	Establishment of national music centers, conservatories, and core musical curriculums	Further reliance on the Western music canon, and increased centrality of romantic music practices/repertoire
Establishment of the Western Classical Music Canon	Formation of the canon during the formation of the discipline in the late 19th and early 20th centuries, prominence of empiricism	Cemented the score as the “work” and object of study, further elevated composers and their works as disciplinary focus.

	at the time.	

The impact of each of these factors cannot fully be explored within the scope of this dissertation. However, the rise in prominence of the musical score and the composer during and following the Romantic period permanently changed the Western classical music world's relationship to music, the score, and the composer.

The centrality and codification of the score as the object of musical study was one of the main impetus that allowed for the creation of a western musical canon and historical narrative. With the written score and the composer as the primary objects of study, performance and the live experience/sonification of the score became a background focus in the discipline of musicology. Perhaps more importantly, the prestige of classical music was now tethered to the image of Romantic composers, their struggle and their musical genius, and the complexity of the score. Imbued with post-Romantic ideals, musicologists studying earlier periods, particularly the medieval and Renaissance period, had to contend with notation that was far less authoritative, composers who could not be identified or didn't match the Romantic definition of a composer, and repertoires that sounded far more simplistic rhythmically, melodically, and harmonically. Musicologists studying these earlier periods constructed narratives of medieval music progressing directly to later musical practices and analyzed early repertoires as precursors to Romantic musical forms in order to conform to post-Romantic ideals of progress and musical development.

Because of the prominence of the Romantic period in foundations of musicology, medieval music has been subsumed by the post-Romantic definition of music despite the inconsistencies and limited information within medieval music scores. This is to say that the medieval score contains so much less information than the contemporary score, sparking many debates as to the accuracy and performance of the score. For instance, debates concerning text underlay and instrumentation in late thirteenth and fourteenth century repertoires such as the motet and *formes fixes* have sparked a wide variety of performance practices and edited volumes.[26] Even the notation of thirteenth-century Notre-Dame polyphony, believed to be more accurate as will be discussed below, can be interpreted as multiple rhythmic modes, seen in examples such as *Sederunt Principes* in Edward Roesner's *Magnus Liber Organi* edited volumes.[27] Medieval notation leaves little consensus as to the performance practice of many repertoires as, unlike modern scores, there are few consistent practices for the notation and documentation of music.

Medieval music's place and role in the canon of western music history further problematizes our understanding of early repertoires. There are two simultaneous ontological challenges on medieval music: first, the need to dispel the conception and notions of "medieval;" second, the placing of medieval music as the beginnings of the Western Music History narrative. Christopher Page, in *Discarding Images* outlines history of the terms "middle ages" and the implications that are embedded in scholarship because of them. Invented by the Renaissance intellectuals, the "Middle Ages" was a derogatory term to separate and elevate the Renaissance from what came

[26] Daniel Leech-Wilkinson, *The Modern Invention of Medieval Music: Scholarship, Ideology, Performance* (Cambridge: Cambridge University Press, 2002),13-87. Dorottya Fabian, "The Meaning of Authenticity and The Early Music Movement: A Historical Review," *International Review of the Aesthetics and Sociology of Music* 32, no. (December, 2001): 13-167. Elizabeth Randell Upton will also be discussing this in her forthcoming monograph which examines "authenticity" in the early music revival of the late twentieth century, and how popular music influenced performance choices in early music recordings.

[27] Edward H. Roesner, ed., *Le Magnus liber organi de Notre-Dame de Paris* 7 vols (Monaco: Editions de l'Oiseau-Lyre, 1993-2009).

before, relegating the Medieval period as the time between the “enlightened” Classical Period and the rise of the Renaissance thinker.[28] The concept of the medieval/Middle Ages, argues Page, created “mental schemes” that are perpetuated by modern scholars such as “efflorescence/decay, elite/popular, literate/non-literate, learned/unlearned and urban/rural.”[29] Furthering our understanding of modern manipulation of the notion of the Middle Ages, in *Inventing the Middle Ages,* Norman Cantor outlines the ways that nineteenth and twentieth century scholars used the Middle Ages in service of current political and social agendas. This can be seen in the construction of historical narratives adapted to highlight the glory of the state or cultural supremacy obscuring historical accuracy and subjugating the medieval in favor of the modern.[30] The medieval period is understood through and compared to the modern, obscuring our understanding of the past on its own.

Compounding the issue, medieval music posthumously became the beginnings of Western Classical Music and, as such, part of a linear progression for the repertoires that would come later. Notions of medieval music’s supposed primitivism—considered such because of its relative melodic, harmonic, and rhythmic simplicity if compared to later works such as symphonies—allowed scholars easily to establish medieval repertoires as mere stepping stones for the compositional practices and prestige of later composer and musical forms. For instance, Friedrich Ludwing (1872-1930), father of medieval musicology, constructed his historical narrative of medieval music to build and

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[28] Christopher Page, *Discarding Images: Reflections on Music and Culture in medieval France* (Oxford: Clarendon Press, 1993).

[29] Ibid., 2.

[30] Norman Cantor, *Inventing the Middle Ages* (New York: Harper Perennial, 1991). See also: David Lowenthal, *The Past is a Foreign Country* (Cambridge: Cambridge University Press, 1985).

progress to highlight the compositional master of Palestrina (1525-1594).[31] Similarly, the so-called "Cyclic Mass," referring to the four parts of the mass ordinary, which in the 15th and 16th centuries was unified by the use of a sacred secular melody in the cantus firmus, was interpreted by Manfred Bukofzer to be a precursor of the symphony. The unification of the melodic material in the cyclic mass was compared to the melodic unity of the four-movement symphony—a perspective that remained largely unchallenged until the 2000s. Medieval music was interpreted as early precursors or foundations for later musical inventions.

Assumed linear progression of medieval repertoires also resulted in the valuation of the genres that did and did not fit into the narrative of the progression of classical music. Genres in the twelfth and thirteenth centuries that feature rhythmic development are valued higher by the discipline than others performed at the time. For instance the creation of discant clausulae to provide the foundation of a motet, once considered to be a one directional progression, Catherine Bradley hypothesizes was a more reciprocal compositional process, requiring a revision of the understanding of an entire musical practice.[32] The need for genres to conform to a narrative of rhythmic development left genres such as the *formes fixes* and *carol(e)* to be devalued despite their pervasive presence in manuscripts.[33] Incorporating medieval music into the western music history narrative was both a way to understand and provide structure to the discussion of

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[31] Anna Maria Busse-Berger, *Medieval Music and the Art of Memory,* (Berkeley: University of California Press, 2005), 15-31.

[32] Catherine Bradley, *Polyphony in Medieval Paris: The Art of Composing with Plainchant* (Cambridge: Cambridge University Press, 2018).

[33] Elizabeth Randell Upton*, Music and Performance in the Later Middle Ages* (New York: Palgrave Macmillan, 2013). Gillian Gower, *The Iconography of Queenship: Sacred Music and Female Exemplarity in Late Medieval Britain* PhD Diss., (University of California Los Angeles, 2016). Robert Mullally, *The Carole: A Study of Medieval Dance* (New York: Ashgate, 2011).

medieval music. However, the drive to create a narrative built on musical progress placed strong biases and limitations on our understanding of medieval music that scholars including Bradley, Busse Berger, and Upton are re-thinking.

Finally, the establishment/advent of the Western Music Canon created a composer-centric focus on western music history, putting yet more pressure on medieval music to conform to our retrospective understanding of later periods. There came a need and desire to validate medieval composers, identifying and contributing works to individuals in order to put medieval composers in conversation with their modern counterparts. A composer-centric narrative also promotes focus on attributing anonymous works to a composer, which can lead to the elevation of specific figures, including Léonin, Josquin des Prez, and Guillaume Du Fay as major nodes in music history and accredits them with sole responsibility for musical development. For repertoires of the twelfth and thirteenth centuries and earlier, a composer-centric narrative results in the erasure of labor, particularly of the singing body, and further devalues musical repertoires that are unwritten and/or seen as peripheral to the canon.

Many scholars since the early 2000s have made strides to reinsert the location and people involved in medieval music making. Scholars such as Bruce Holsinger in 2001 and Susan McClary in 2002 examine the body of the performer and composer through the music's contemporary and current issues and anxieties towards gender and sexuality.[34] These studies highlight how the physicality of music—in performance, composition, and listening—cannot be separated from the written record, as the physicality of performing and listening are contained within the score. The score's

[34] Bruce Holsinger, *Music, Body, and Desire in Medieval Culture* (Stanford: Stanford University Press, 2001). Susan McClary, *Feminine Endings* (Minneapolis: University of Minnesota Press, 2002).

record of the bodies that produce them is investigated in studies such as Emma Dillon's 2002 monograph *Medieval Music-making and the Roman de Fauvel*. Scores, argues Dillon, are the result of singing/performing and scribal bodies, as the manuscript contains a version of musical practices told by a select few scribes.[35] Studies such as those of Holsinger and Dillon demonstrate the shift in scholarship to examine the medieval contexts and practices surrounding musical production and performance, as well as issues of agency and the separation of scribal products and performance practices.

Musicological studies are able to consider the sound, body, and performance location to an even greater extent with the inclusion of methods from Sound Studies. Sound Studies emerged in the 2000s as a new discipline to examine sound—the music and non-musical phenomena—its production, reception, materials surroundings, and medium.[36] Combining methodologies from a diverse array of disciplines, including

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[35] Emma Dillon, *Medieval Music-making and the Roman de Fauvel* (Cambridge: Cambridge University Press, 2002).

[36] Sound Studies has roots in the 20th century with foundational works such as Murray Schafer, Martin Heidegger, and Walter Ong, who strove to investigate the changing soundscapes and sounds of the industrialized world. Early sound studies scholars examined and worked to preserve the materiality and, in some cases the religiosity of the pre-industrialized world. These early scholars also examined the developing technology and auditory cultures that both produced and captured sound and noises and our relationship to them. Murray Schafer coined the term soundscape in 1977 as he analyzed the changing sounds of the city during the increase of factories, machinery, and industry in *The Tuning of the World* (1977) and reprinted as *The Soundscape: Our Sonic Environment and the Tuning of the World* (Rochester: Destiny Books, 1993). See also: Murray Schafer, *The Music of the Environment* (Wien: Universal Edition, 1973). Barry Truax, *Handbook for Acoustic Ecology* (Vancouver: World Soundscape Project, Simon Fraser University, and ARC Publications, 1978). Walter Ong, *The Presence of the World: Some Prolegomena for Cultural and Religious History* (New Haven: Yale University Press, 1967). Additionally, sound studies has also included considerations of 19th century listening cultures and the development of sound technology including the gramophone, stethoscope, and other recording technologies. See: Daniel Morat, ed., *Sounds of Modern History: Auditory Cultures in 19th- and 20th-Century Europe* (New York: Berghahn, 2014). Trevor Pinch and Karin Bijsterveld, eds., *The Oxford Handbook of Sound Studies* (Oxford: Oxford University Press, 2012). Michael Bull, ed., *The Routledge Companion to Sound Studies* (New York: Routledge, 2019). Jonathan Sterne, *The Audible Past: Cultural Origins of Sound Reproduction* (Durham: Duke University Press, 2003). Jonathan Sterne, ed., *The Sound Studies Reader* (New York: Routledge, 2012). Smith, *Hearing History*.

music, musicology, media studies, etc., sound studies is able to analyze sound outside of musicology's relatively narrow definition of music. Within sound studies, sound is always reliant on the means of production and reception which are affected by the materials present. As such, the location and means of performance are central to the investigations of sound studies scholars. Incorporating sound studies with musicology allows for new, and deeper inquiries into the relationships between the performer, sound, and the musical score. For instance, Nina Eidsheim and Dillon examine how notation succeeds and fails to capture the physicality of performance.[37] Both Eidsheim and Dillon analyze the performance location and conditions as part of their investigation of the physicality of performance. The impact and influence of the location on performance has additionally been examined in studies such as *Hearing Places* in which musicologists and composers alike investigate the sonic qualities of the concert hall, caves, or natural environments they record or perform within.[38] In *Hearing Places,* scholars such as Colin Ripley, Dolly MacKinnon, and Ros Bandt investigate the acoustics and sonic features of their performance environment, examining the materials and architecture to better adapt or create music within the space. Medieval historians similarly examine features within a performance space, most prominently churches and cathedrals, to examine the sound(s) captured in the engravings, images, and sculpture within churches and cathedrals.[39] These artistic features, when considered together with the musical and liturgical practices performed within the church or cathedral, provide

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[37] Eidsheim, *Sensing Sound*. Emma Dillon, *The Sense of Sound: musical meaning in France* (New York: oxford University Press, 2012).

[38] Ros Bandt, Michelle Duffy, and Dolly MacKinnon, eds., *Hearing Places: sounds, place, time and culture* (Newcastle: Cambridge Scholars Publishing, 2007).

[39] Susan Boyton and Dieane J. Reilly, eds., *Resounding Images: medieval intersections of art, music, and sound* (Turnhout: Brepols, 2015).

evidence of the intricate practices of a particular chapter or symbolize the effects of the sounded practices. As demonstrated with this small sample of studies, sound studies provides multiple methods for examining the production and perception of sound in a specific performance space.

The science of acoustics also allows me to expand my consideration of the materiality and behavior of sound. Acoustics provides methods to measure sound waves and their behavior in a performance space. The ability to produce, measure, and analyze acoustic qualities such as reverberation, early and lateral reflections, as well as clarity, envelopment, and intimacy enables the quantitative measure of how a sound or sounds interacts within the performance space.[40] Acoustic technology and measurements can also account for different performance variables, such as the number of performers, the type of repertoire, and the volume of sound being produced, allowing for a more holistic understanding of a music repertoire within a specific space. Further, seen in studies such as those of Gerstel, Pentcheva, and St Paul's digital recreation mentioned above, applying acoustic technology to historical spaces allows for new inquiries and understanding of performance practices in spaces previously unconsidered or undervalued.[41] Incorporating acoustic measurement enables the analysis of how musical features interact with the materials in the cathedral space. When combined with the analysis of the performing bodies within space made possible by sound studies, I am able to examine the production, vibration, and reception of sound within Notre-Dame.

[40] Beranek, *Concert Halls*. Thompson, *Soundscape of Modernity*. Hall, *Architectural Acoustics.*

[41] This will also be discussed in more detail in Chapter Three.

Notre-Dame: Source Materials

To examine the production of sound within Notre-Dame I must rely on a variety of sources that discuss performance practice at the cathedral. Extant sources and information about musical practices at Notre-Dame include five musical treatises, five music manuscripts, and archival records. The five musical treatises, likely copied in Paris, are dated to the thirteenth century and outline the rhythmic and notational practices that allowed the music manuscripts to be interpreted and transcribed. Musicologists consider all five treatises, to be discussed below, as the core of the modern understanding of Notre-Dame notation and rhythmic practices during the thirteenth century. Other treatises from the thirteenth century are still extant, including the *Summa Musica* but were likely not from France and are excluded from consideration.[42] The music manuscripts contain the polyphonic music settings and all five come from the thirteenth century, meaning that earlier practices have either been erased, replaced, altered, or are not fully recorded. Further, the music manuscripts contain a development of thirteenth-century rhythmic and notation practices, as will be discussed below. Finally, the archival records provide insight into the singers, their training, and performance practices at the cathedral. As these sources demonstrate, information about musical practices at Notre-Dame cathedral are in many ways well preserved, yet there are many gaps in our early knowledge of the institutions and its practices. In what follows, I outline what is known about the extant sources including the

[42] The *Summa Musica* was also copied in the thirteenth century. However, because the manuscript was likely copied in the Holy Roman Empire and the authorship is uncertain it is not often considered in analysis and comprehension of Parisian practices. See: Christopher Page ed. and trans., *Summa Musica: A Thirteenth-Century Manual for Singers* (Cambridge: Cambridge University Press, 1991), 1-12.

thirteenth-century music treatises, manuscripts, musical development, and the singers, performance practice, and their training.

The Treatises

Musicologist's ability to comprehend the notation and rhythmic practices of Notre-Dame polyphony has been developed by studying five music treatises from the thirteenth century. The five treatises are as follows: *Musica Plana* attributed to Johannes de Garlandia, the *Ars Musica* attributed to Magister Lambertus, *The Art of Measurable Song* attributed to Franco of Cologne, *Musica mensurata* attributed to Anonymous of St. Emmeram, and the titleless music treatise attributed to Anonymous IV. The treatises, note scholars such as Busse-Berger and Yudkin, are dedicated to the notation of music as much, if not more, than the composition of polyphony. Each treatise dedicates a discussion (of vastly different lengths) to the rhythmic modes and *tempus* (time and the division of time), the ligation of the modes in notation, and the concordances. The five treatises, when compared, outline the change in notational practice, rhythmic practices, and changes in concordance within just a thirty or so year period.

Scholars have identified two schools of thought in the five treatises: Johannes de Garlandia, who lays the foundational teachings followed by Anonymous of St. Emmeram and Anonymous IV, and the notational developments of Lambertus and Franco of Cologne that allows for more rhythmic flexibility. Garlandia, and the Anonymi following his teachings, use the same six rhythmic modes and notational system. However, as seen in Table 1, Lambertus has a different number and organization of the rhythmic modes. Additionally, Lambertus includes three unique modes to address the rhythms found in the music repertoire of Paris. These modes are not included in the other treatises as the Anonymous authors reject them in favor of Garlandia's teachings, while Franco of Cologne chose to simplify the modes of Lambertus within his own system.[43] Amongst the five treatises, there is little consensus as how to best notate new rhythmic development. These treatises further highlight the changes and rapid development occurring in music through the thirteenth century.

Table 0.2: Rhythmic modes in Garlandia, Lambertus, and Franco

Author									
Johannes de Garlandia	5	1	2	3	4	-	6	-	-
(rhythm)	LLL	LB	BL	LBB	BBL	SSBB	BBB	SS	SSS
Lambertus	1	2	3	4	5	6	7	8	9
Franco	1a	1b	2	3	4	-	5	-	-

Table Credit: Christian Meyer, *The 'Ars Musica' Attributed to Magister Lambertus/Aristoteles,* xxxii.

The treatises are most concerned with the notation of the rhythmic modes and their rhythmic formulae. The majority of all five treatises are dedicated to discussing the *tempus* or duration of rhythmic values in each mode, notating the rhythmic variants in each mode, and the ligation of each mode. Such an emphasis on the notation indicates that the writers were primarily concerned with how to record polyphonic practices, seen best in the treatise of Anonymous of St. Emmeram who cautions and scolds scribes and secular musicians against notating music incorrectly.[44] The thirteenth century, as revealed by the five music treatises, was a time of notational and rhythmic development

[43] Christian Meyer ed., *The 'Ars Musica' Attributed to Magister Lambertus/Aristoteles*, Karen Desmond, trans. (Farnham: Ashgate Publishing Co.: 2015), xxxii-xxxiii.

[44] Anonymous of St. Emmeram, *De Musica Mensurata*, Jeremy Yudkin, ed. And trans. (Bloomington: Indiana University Press, 1990).

that was captured in varying degrees by the five music manuscripts to which we now turn.

The Music Manuscripts

Knowledge of the musical development and polyphonic practices at Notre-Dame cathedral comes primarily from the five extant thirteenth-century music manuscript sources: Wolfenbüttel 1 (Codex. Guelf. 628 Helmst, referred to as W1), Florence (Pluteus 29.1, referred to as F), Wolfenbüttel 2 (Cod. Guelf. 1099 Helmst, referred to as W2), the Madrid Codex (E-Mn 20486, referred to as Ma) and LoA (London, British Library, Egerton 2615). Each manuscript contains a variant of the repertoire, allowing scholars to note rhythmic development. However, the differing contents and provenance of each manuscript has also led scholars to create a hierarchical focus on select manuscripts sources: F and W2, which contain the largest number of settings. The contents of F, W2, and W1 has further been used to hypothesize the contents of the *Magnus Liber Organi*, the Great Book of Organum from Notre-Dame cathedral that is now lost to history. Discussions on the exact contents of the *Magnus Liber* have also served to examine the development of the repertoire through a written perspective. In what follows, I introduce all five sources, however my dissertation will focus only on the repertoire of W1 and F, as will be discussed below.

Musicologist Mark Everist's revision of the copy date for Wolfenbüttel 1 not only places the manuscript earlier in the century, but also indicates an even earlier exemplar and thus repertoire. W1 is the earliest surviving manuscript source of Notre-Dame polyphony and as such it has also received the most paleographic study, in part because it is the earliest source, but also for the complexities in dating the manuscript.

Initial studies, including Rebecca Baltzer's, dated the manuscript to circa 1240-1250 through an examination of the marginalia, initials, handwriting, and page layout.[45] However, Everist's analysis of these same elements, and historiography of the figures at St. Andrew's priory where the manuscript was copied, revised the copy date to the 1230s.[46] W1 contains just over 300 settings, in the surviving 197 folios of the manuscript.[47] W1 contains a wide variety of polyphonic works, including—in manuscript order—four, three, and two voice organa and copula, discant clausulae, conductus, sequences, and monophonic works. W1 is named for its later provenance, having moved to Wolfenbüttel library in 1597, along with W2. The settings in the manuscript are organized first by the number of voices and then by the liturgical calendar. As will be discussed below, this earlier dating elucidates the differences in repertoire between W1 and F.

Scholars such as Heinrich Husmann and Hans Tischler consider the Florence Manuscript to be the most complete and therefore most important source of Notre-Dame polyphony because it contains the largest amount of polyphony of all the

[45] Rebecca Baltzer, "Thirteenth-Century Illuminated Miniatures and the Date of the Florence Manuscript," in *journal of the American Musicological Society* 25 (1972), 1-18. See also: Robert Branner, "Johannes Grusch Atelier and the Continental Origins of the William of Devon Painter," in *Art Bulletin* 54 (1972), 24-30.; Léopold Delisle "Discours," *Annuaire-bulletin de la Société de l'Histoire de France* 22 (1885), 82-139; Friedrich Ludwig, *Über den Entstehungsort der grossen 'Notre-Dame-Handschriften'* (Wien: Universal Edition, 1930), 45-49.

[46] Mark Everist, "From Paris to St. Andrews: The Origins of W1,"*Journal of the American Musicological Society* 43, no 1(Spring 1990), 7-10.

[47] For the number of pieces and foliation see https://www.diamm.ac.uk/sources/924/#/

Notre-Dame sources.[48] Copied in Paris, possibly between 1240 and 1255,[49] F contains almost nine hundred settings in twenty-seven extant gatherings—just over four hundred folios, having lost thirty-six folios.[50] These folios contain many types of polyphony including four, three, and two voice organum, conductus, clausulae, and motets. The scribes of F incorporated room for yet more pieces, as each gathering ends with blank staves indicating the inclusive and thorough nature of the manuscript. The importance of F is also indicated by its provenance. The ownership of F before the fifteenth century is speculative, but Everist hypothesizes a royal connection, from the blue and gold fleurs-de-lys in the illumination on folio one.[51] In the second half of the fifteenth century F was purchased by the Medici family, then moved to San Marco (1494), the library of Pope Leo X (1508), and was returned to Florence to the library of San Lorenzo in 1521.[52] The Medici ownership of this manuscript indicates the prestige of the Parisian repertoire through multiple centuries. However, some question remains as to the function of F and W1.

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[48] Barbara Haggh and Michel Huglo, "*Magnus liber—Maius munus:* Origine et destinée du manuscript F," *Revue de musicologie* 90 (2004), 193-230. Husmann, "The Origin and Destination of the Magnus liber organi." Heinrich Husmann and Andres P. Briner, "The Enlargement of the 'magnus liber organi' and the Paris Churches of st. Germain l'Auxerrois and Ste. Geneviève-du-Mont," *Journal of the American Musicological Society* 16, no 2 (Summer 1963), 176-203. Roesner, *Le Magnus Liber Organi*, xx1. Hans Tischler, "The Evolution of the 'Magnus Liber Organi,'" *The Musical Quarterly* 70, no 2 (Spring 1984), 163-174. Friedrich Ludwig, *Repertorium organorum recentioris et motetorum vetustis stili* (New York: Institute of Medieval Music, 1964-78). Craig Wright, *Music and Ceremony at Notre Dame of Paris, 500-1500* (Cambridge: Cambridge University Press, 1989).

[49] Mark Everist, *Polyphonic Music in Thirteenth-Century France: Aspects of Sources and Distribution* PhD diss. (University of Oxford, 1985) and "From Paris," 84.

[50] Those being folios 48-64, 94, 185-200, and 255-256.

[51] Everist, *Polyphonic Music*, 84-85.

[52] Ibid., 61-62.

The precise use of W1 and F is unclear, raising questions as to the performance practices around both manuscripts. Everist discusses the possibility of W1 being present either in the cathedral of St. Andrews itself, supported by the fourteenth-century marginalia, or part of Bishop's episcopal *capella*, in this instance referring to "the collection of ritual items that would have accompanied the Bishop."[53] If the manuscript was located in the cathedral, this would indicate the manuscript was in use at St. Andrews cathedral, as opposed to W1's presence as part of the Bishop's *capella*, in which the manuscript could have functioned more as a "musico-liturgical icon rather than as a source for performance."[54] Florence has been labeled as a reference copy, possibly meant for the purpose of study based on the inclusive nature of the manuscript and the quantity of setting included.[55] Whether performed from or used as reference copies, both manuscripts were meant to record the repertoire and polyphonic practice at a specific moment in time.

Ma and LoA are two of the lesser studied Notre-Dame sources. Ma is the smallest of the sources, containing just over one hundred pieces, and was copied and kept at Toledo. Copied in the second half of the thirteenth century in Toledo, Ma is chronologically placed between the F and W2, dating the manuscript between 1230 and 1260. Ma contains only 142 folios, not all of which were part of the original manuscript.[56]

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[53] Everist, "From Paris," 30-31.

[54] Ibid., 31.

[55] From my own observations the wear patterns suggest a lightly used manuscript, but one perhaps stored improperly as much of the dirt and staining is located only at the top binding of the manuscript. The most worn pages are those at the ends of gatherings, suggesting that the manuscript perhaps remained unbound for some time.

[56]Juan Carlos Asensio Palacios, *El Códice de Madrid, Biblioteca nacional, Mss. 20486: Polifonías del Siglo XIII* (Madrid: Fundación Caja: Editorial Alpuerto, 1997), 11-28. Jutta Pumpe, "Die Motetten der Madrider Notre-Dame-Handschrift," *Münchner Veröffentlichungen zur Musikgeschichte* 48 (1991). María del Carmen Gómez Muntané, *La música medieval en España* (Kassel: Reichenberger, 2001), 118-125.

Pierre Aubry suspected that the first twenty-four folios were added later, based on the large decorated initial on folio 25r.[57] Ma transmits only a small portion of Notre-Dame polyphony including Pérotin's *quadrupla Viderunt Omnes* and *Sederunt* as well as the four-voice conductus *Mors.* Most of the contents of Ma are congruent to W1, while the majority of the codex pertains to the cathedral it was intended for in Toledo, which has led scholars to consider Ma as less central to the discussion of Notre-Dame polyphony. LoA was likely copied in the same Parisian workshop as F and around the same time.[58] LoA has the same layout and formatting as F (1227-1234), but contains only twenty settings.[59] Though it was copied in Paris, LoA contains such a small amount of polyphonic settings, LoA is a less prominent manuscript in discussion of Notre-Dame's repertoire.

W2 is the latest of the Notre-Dame sources, and, both for its size and the repertoire it contains, has been viewed as one of the most central sources of Notre-Dame polyphony. W2 manuscript was copied in Paris in the 1250s or later and

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Javier Sastre González, "El *Códice de Madrid* (E-Mn 20486) y su repertorio de polifonía medieval: un estado de la cuestión," *En la España Medieval* 43 (February, 2020), 119-148.

[57] Pierre Aubry, *Cents Motets du XIIIe siècle* 3 vols. (New York: Broude Bros., 1964). Pierre Aubry, "Iter Hispanicum...II. Deux Chansonniers français à la Bibliothèque de l'Escorial," *Sammelbände der internationalen Musikgesellschaft* 8 (1907), 337. See also Higinio Angles, *El Codex musical de las Huelgas* 3 vols (Institut d'Estudis Catalans: Biblioteca de Catalunya, 1931).

[58] Everist, *Polyphonic Music in Thirteenth-Century France*, 66-68, 86-89. Gregorio Bevilacqua, "The Earliest Source of Notre-Dame Polyphony?: A New Conductus Fragment from the Early Thirteenth Century," *Music and Letters* 97, no. 1 (February, 2016), 1-41. DIAMM and the British Library Archives list the copy date as 1227-1234. https://www.diamm.ac.uk/sources/918/#/bibliography and http://searcharchives.bl.uk/primo_library/libweb/action/display.do?tabs=detailsTab&ct=display&fn=search&doc=IAMS032-001983588&indx=1&recIds=IAMS032-001983588&recIdxs=0&elementId=0&renderMode=poppedOut&displayMode=full&frbrVersion=&dscnt=1&frbg=&scp.scps=scope%3A%28BL%29&tab=local&dstmp=1400668258421&srt=rank&mode=Basic&dum=true&vl(freeText0)=Egerton+2615&vid=IAMS_VU2

[59] Ibid. footnote 55.

found its way with W1 to Wolfenbuttel library in 1597.[60] Containing a little over three hundred pieces in 253 folios, W2 has a wide variety of genres including organum, conducti, clausulae, and the most motets of any of the Notre-Dame sources—over two hundred of them.[61] Additionally, W2 features not only a shift in genre, as seen with the additional motet, but also rhythmic and melodic variations in *duplum* settings in particular.[62] The large number of motets, the increased rhythmic variants in settings (when compared to W1 and even F), but particularly the number of concordances between F and W2, has made W2 a prominent manuscript in the study of Notre-Dame polyphony.

Finally, there is one other manuscript to be discussed: the *Magnus Liber Organi.* The contents of the *magnus liber* has been hypothesized many times over from the contents of W1, W2, and F. Our knowledge of the existence of the *magnus liber* comes from a statement from the treatise of Anonymous IV which states:

> ...Léonin...who made the great book of *organum* from the gradual and antiphonary to elaborate the divine service. And it was in use up to the time of Pérotin the Great, who edited it and made very many better *clausuale* or *puncta*...The book or books of Master Pérotin were in use up to the time of Master Robertus de Sabilone, and in the choir of the Parisian cathedral church of the Blessed Virgin, and from his time up to today.[63]

[60] Everist, *Polyphonic Music in Thirteenth-Century France*, 99-110, 218. Rebecca Baltzer, in "Thirteenth-Century Illuminated Miniatures," *Journal of the American Musicological Society* 25, no. 1 (1972) has also dated the manuscript to 1260-75.

[61] Répertoire Internationale des Sources Musicales and DIAMM editors, January 23, 2017, https://www.diamm.ac.uk/sources/854/#/contributors

[62] Roesner, *Le Magnus Liber Organi*, xix-xcvi. Edward Roesner, "Who 'Made' the *Magnus Liber*?," *Early Music History* 20 (2001), 254-256.

[63] Yudkin, *The Music Treatise of Anonymous IV,* 39-40.

Modern scholars trying to identify the contexts of the *liber* agree that it contained polyphonic settings for each feast in the liturgical calendar that received polyphony.[64] The exact contents vary from study to study, however is there agreement among scholars that the *magnus liber* changed with each iteration and edit described by Anonymous IV.[65]

Though the extant manuscripts preserve hundreds of settings, missing sources from the twelfth century limit our knowledge of Notre-Dame polyphony. As scholars such as Dillon, Busse-Berger, and Rebecca Baltzer have observed, the limitation of sources and temporal distance between performance and the written record of settings restricts our ability to fully comprehend the musical practices at Notre-Dame cathedral in the twelfth century. The limitations of sources is exemplified by the seventeen lost manuscripts of Notre-Dame polyphony identified by Baltzer. Of the seventeen, none were copied before the 1230s. The only known exception is the bifolia used as flyleaves found by Gregorio Bevilacqua in Troyes 1471, copied in the first quarter of the thirteenth century, he arges. The bifolia contains the same repertoire and layout of the Parisian copied manuscripts F, W2, and LoA, though the bifolia does not contain notation, leaving many unanswered questions. With no traceable source material before the thirteenth century, the gap in sources forces reliance on later manuscripts to discuss an earlier practice.

[64] To date, scholars have concluded this repertoire is the concordances between, primarily, W2, and F (of which there are over three hundred between F and W2 alone), or the contents individual to each manuscript, as some scholars hypothesized each manuscript to be the changing version of the *Liber*. See: Edward Coussemaker, 1886. Husmann, "The Origin and Destination." Husmann and Briner, "The Enlargement of the 'Magnus liber organi.' Tischler, "The Evolution of the 'Magnus Liber Organi.'" William G. Waite, "The Abbreviation of the *Magnus Liber*," in *Journal of the American Musicological Society* 14, 147-58. Roesner, "Who 'Made' the *Magnus Liber,*" 227-66. Wright, *Music and Ceremony,* 243-258.

[65] Ibid., footnote 65.

Even more problematic, none of the surviving sources are believed to be recorded for Notre-Dame cathedral itself, creating more distance between the sources and musical practice. Both Baltzer and Wright note "the absence of *any* polyphonic manuscripts from the list of choirbooks, the inventories of the library, the treasury, the bishop's chapel or chapter house of Notre-Dame."[66] The one surviving mention of a manuscript source comes from the thirteenth-century music treatise of Anonymous IV.[67] While the repertoire within the surviving sources derive from the *Magnus Liber*, the variance between each manuscript suggests a continuing development of the repertoire at the cathedral. To date, no conclusion has been reached as to explain the absence of a polyphonic source at the cathedral. As will be discussed in chapter one, a possible explanation is the coexistence between written, oral, and improvisatory practices at the Notre-Dame cathedral. The changes between the surviving manuscripts suggest an ever evolving repertoire, the full extent of which we may never know.

Music Development

Musical development in polyphony has been defined as increased rhythmic complexity by musicologists such as William Waite, Ernest Sanders, and Edward Roesner. Through the twelfth and thirteenth centuries, polyphonic music at Notre-Dame transformed from florid organum to the stricter rhythms of discant. The incorporation of discant (a note-to-note rhythmic texture) into the Notre-Dame repertoire at the end of

[66] Busse-Berge, *Medieval Music,* 163.

[67] Jeremy Yudkin, ed. and trans., *The Music Treatise of Anonymous IV: A New Translation* (Stuttgart, Hanssler-Verlag: 1985), 39. Anonymous IV records that the famed *Magnus Liber Organi* — the big book of organum — was at the cathedral and in use "up until the time of Master Robertus de Sabilon...And from his time up to today." Additionally, Anonymous indicates the liber underwent at least two versions: the first by Léonin, master of organum, who made the first version, and the second by Pérotin, master of discant, who edited the first version and added many new discant settings.

the twelfth century for scholars such as Waite, Sanders, Roesner, and Wright marked significant musical development. Creating the rhythmic coordination between voice-parts, argues scholars including Sanders and Leo Trietler, required a written composition and performance from the manuscripts. As such development is solely contained within the manuscripts and further defined by the thirteenth-century music treatises discussed above. Features such as the advent of new rhythmic modes, more rhythmic flexibility in notation, and the definitions and development of new genres such as *copula* and *discant* provide the foundation of polyphonic development in the twelfth and thirteenth century. Between W1, F, and W2, the same polyphonic settings can contain different rhythmic modes, seen in settings such as *Sederunt Principes*, and has been interpreted as proof of rhythmic, and thus musical development. Indeed, the advancement of rhythmic notation and the development of new musical genres frame the musicological discussion of musical development during the twelfth and thirteenth centuries.

However, our ability to track development through the emergence of new musical genres is encumbered by conflicting and unclear definitions of genres, particularly *organum* and *copula. Organum* was a genre of music that had several sub genres - the definitions of which changed between treatises, obscuring our modern understanding of the genres. Anonymous IV, as noted by musicologists such as Yudkin and Sanders, often obscures the definitions presented by Garlandia by either omitting parts of the definition or using confusing language.[68] However, it must also be noted that the modern

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[68] Jeremy Yudkin, "The *Copula* According to Johannes de Garlandia," *Musica disciplina* 34 (1980): 67-84. Jeremy Yudkin, "Anonymous of St. Emmeram and Anonymous IV on the "Copula,"" *The Musical Quarterly* 70, no. 1 (Winter, 1984): 1-22. Ernest Sanders, "Consonance and Rhythm in the Organum of the 12th and 13th Centuries," *Journal of the American Musicological Society* 33 (1980): 274-286.

understanding of the genre delineations and rhythmic practices have been equally obscured by inaccurate translations and transcriptions in critical editions.[69] In this study, I will use the definitions of *organum* and *copula* set forth by Yudkin's study of the music treatises. *Organum* has many sub-types including: *organum speciali* (a broader category that includes *organum per se* and *organum cum alio*), *organum per se* or *organum purum* ("not governed by modal rhythm; it moves in its own manner; and the length of the notes is determined by the penultimate, by concord, and by notation"), and *organum cum alio* (performed according to (some) *mensura* or measure, when combined with another *organum* can take on the rhythm of discant).[70] The types of *organum* are measured through a combination of measured and unmeasured rhythmic techniques, the interpretation of which has caused great debate for the purpose of transcription.[71] Discant, with the most clear definitions, is defined by Anonymous IV as "the concordance of certain diverse melodies" coordinated by modal rhythm in all voices including the tenor.[72] The definition of *Copula* has been particularly complicated for scholars to define from the medieval treatises. *Copula* was "a species of music in modal rhythm over a held tenor-tone, characterized by sectionalization and melodic sequence" and, Yudkin interprets, attached to specific performance practices and "with the application of modal rhythm to *organum purum* in the mid-thirteenth century...the

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[69] Jeremy Yudkin, "The Rhythm of Organum Purum," *The Journal of Musicology* 2, no. 4 (Autumn, 1983), 355-359. Edward H. Roesner, "Johannes de Garlandia on *Organum in speciali,*" *Early Music History* 2 (1982): 129-160.

[70] Ibid., 365-366.

[71] Ibid., 366-368.

[72] Yudkin, *The Music Treatise of Anonymous IV*, 65.

distinction between *organum purum* and *copula* began to appear meaningless."[73] The ambiguous definitions of *copula* have limited its inclusion in musical development, as beyond the *copula* being in between discant and organum, it is unclear precisely what the genre is. The ambiguous definition and development of the genres certainly indicate the rhythmic fluctuation and hybridity of polyphonic practices at Notre-Dame of Paris.

There are additional genres of music at the cathedral, the presence of which must be factored in the overall musical development of polyphony: the sequence, conductus, and motet. The sequence is an eleventh century genre with a clear melodic form (AA BB CC DD) with liturgical non-liturgical texts. Evidence of sequences performed at Notre-Dame come from recorded sequences attributed to Adam of St. Victor cantor at Notre-Dame recorded in Paris BNF, lat. 14506.[74] The conductus is a genre that features latin poetic texts often set to homorhythmic settings of one to four voices.[75] Neither the sequence or conductus feature much rhythmic complexity, which has prompted scholars studying rhythmic development as musical development to limit or exclude these genres for their discussions.[76] Motets, however, contain the exact type

[73] Yudkin, "The "Copula" According to Johannes de Garlandia," 67-84. Yudkin, "The Anonymous of St. Emmeram," 3.

[74] Margot Fassler, "Who was Adam of St. Victor? The Evidence of the Sequence Manuscripts," *Journal of the American Musicological Society* 37, no 2 (Summer 1984), 233-269. See also: Margot Fassler, "The Role of the Parisian Sequence in the Evolution of Notre-Dame Polyphony," *Speculum* 65, no. 2 (1987): 240.

[75] Margot Fassler, *Music in the Medieval West*: *Western Music in Context* (New York: W. W. norton and Company, 2014), A35.

[76] Here we can again see the detriment of the linear progression narrative in music history as genres have been sorted into central or peripheral categories, as genres interpreted as not contributing to the development of rhythmic notation are of lesser importance, and therefore peripheral. Work has been done to remove the barriers between central and peripheral seen in the studies of Margot Fassler's and Mary Chanen Caldwell's analyses of the sequence and conductus. Fassler's analysis of the sequence and Caldwell's investigation of conducti reconnect the musical practices of the two genres as part of the oral and aural music culture in Paris, which the singers at the cathedral participated within. Not to mention that in the thirteenth century the conductus was a prominent genre in the repertoire at Notre-Dame. See:

of rhythmic complexity lauded in polyphonic practices at Notre-Dame. The motet is a genre that features a different text in each of the two to four voice parts sung over a tenor voice often drawn from a plainchant or clausulae.[77] How and when the liturgical motet would have been sung at Notre-Dame is not clear, however the number of recorded motets in Notre-Dame sources suggests that it was performed at the cathedral.[78] The rhythmic and textural complexity of the motet is often seen by musicologists including Tischler and Ursula Gunther as a new level of musical development.[79] The sequence, conductus, or motet represent a significant portion of the cathedral's musical practices in tandem with *organum, copula,* and *discant*.

The Singers and Their Training

Contributing to the musical repertoires and polyphonic development at Notre-Dame are the singers. Our knowledge of the number of singers, types of singing positions, and performance practice at the cathedral is gleaned from archival documents primarily from the fourteenth and fifteenth centuries. As such, the training and performance practices of the twelfth and early thirteen centuries are hypothesized from music treatises, including those discussed above, and the later archival sources. Our knowledge of the education and training process, information about the groups and

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Fassler, "The Role of the Parisian Sequence." Mary Channen Caldwell, "Cueing Refrains in the Medieval Conductus," *Journal of the Royal Musical Association* 143, no. 2 (2018): 273-324.

[77] Fassler, *Music in the Medieval West*, A39. Mark Everist, "The Thirteenth Century," in *The Cambridge Companion to Medieval Music,* Mark Everist, ed. (Cambridge: Cambridge University Press, 2011), 77.

[78] Tishcler, "The Evolution of the 'Magnus Liber Organi.'" Bradley, *Polyphony in Medieval Paris: The Art of Composing with Plainchant* (Cambridge: Cambridge University Press, 2018), 49-80 & 111-178.

[79] Ursula Gunther, "The 14th-Century Motet and Its Development," *Musica Disciplina* 12 (1958): 27-58. Hans Tischler, "Some Rhythmic Features in Early 13th-Century Motets," *Revue belge de Musicologie/Belgisch Tijdschrift voor Muziekwetenschap* 21, no. 14 (1967): 107-117.

types of singers such as the Matins clerks, provides limited insights into the performance practice of the twelfth century. What can be seen from the documentation available is that there were multiple singing positions at the cathedral, each responsible for performing a portion of the repertoire. Below is an outline of the singers, what is known of their training, and performance practice at Notre-Dame.

Choir boys

One of the first potential steps in the education and training of clerical polyphonic singers was that of a choir boy. The training of choir boys in Paris dates back beyond the Carolingian period and continued throughout the Middle Ages. Documentation of the role of the choir boys at "Notre-Dame" can be found beginning in the eleventh century, and doctrines for the education of these students survives from the early fifteenth century.[80] Beginning in the late eleventh century, the choir boys were enlisted to sing important chants in the divine offices including the psalms and antiphons at Matins, and the *Benedicamus domino* at Lauds, Vespers, and Compline.[81] The boys, in Paris as elsewhere, were educated, clothed, housed, disciplined, and served at the cathedral. Their education consisted of grammar, rhetoric, and music through oral presentation from a master, and memorization.[82] In fact, "the capitular acts at Notre Dame...make no mention of slates or wax tablets upon which to write, and it was not until the seventeenth century that the canons of Paris provided an instructor in writing for the

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[80] Wright, *Music and Ceremony*, 166.

[81] Ibid., 166.

[82] Ibid., 174.

boys."[83] Choir boys were expected to learn a large amount of material, using available mnemonic devices such as the Guidonian hand and the hexachord system.[84] The boys could also advance in rank and within the church. *Spe*, choir boys whose voices had matured, were enlisted to help train the and rehearse the choir boys. These young men could also advance to college and, later, university, and were expected to continue singing in services at the cathedral, and expand their knowledge of the repertoire. Thus, many of these singers advanced into the ranks of the Clerks of Matins.

Matin Clerks

The clerks of Matins were responsible for the majority of singing at Notre-Dame cathedral. These clerks, named for being the members responsible for singing the Matins service, were rather small in number, and varied in age and rank. Of the clergy at Notre Dame, "no one was more familiar with the chants of Notre Dame than the clerks of Matins and lesser canons who sang them daily."[85] There were two tiers of Matins singers: Machicotus, the senior clerks who did much of the solo singing and polyphonic improvisation;[86] and the unadorned Clerks of Matins, who were greater in number.[87] Many of these clerks were young men, those who had just advanced form the ranks of choirboys, or were former choirboys studying at University at the cathedral's expense and expected to sing in return. As an unbeneficed position, the clerks of Matins

[83] Ibid., 175.

[84] Busse-Berger, *Medieval Music*, 47-110.

[85] Wright, *Music and Ceremony*, 173.

[86] Although this term isn't fully defined, these singers: "...appear to have embellished and filed in above the given plainsong, creating polyphony." Wright, *Music and Ceremony,* 25.

[87] Ibid., 25.

were in a precarious position, as they were required to resign annually to re-audition to reclaim their position.[88] However, this process is not necessarily to select only the most talented singers, but possibly to select the most reliable to uphold the tradition, as the clerks of Matins were also some of the most reliable, as records indicate.[89] Nevertheless, the Matins singers were likely the most experienced, and possibly most "talented" singers in both monophonic and polyphonic singing.

Polyphonic singers

The precise identity and training of the polyphonic singers is unknown, but it is clear that by the end of the twelfth century these singers played a large part in the liturgy of Notre-Dame. The polyphonic singers of Notre Dame cathedral were not necessarily separate from the clerks of Matins, and could have included the choirboys or other clergy members. Wright's study indicates that the polyphonic singers may have been selected for specific qualities including reliability, punctuality, and ability to memorize the repertoire over singing ability. Just as the choir boys were expected to memorize the psalms and liturgy, so too were the polyphonic singers. Wright notes that in the fourteenth century new singers at the cathedral, those hired from outside the chapter, were required to memorize the repertoire within six months of their hiring at the cathedral emphasizing the importance placed on memorization.[90] Some skill in memorization and improvisation would have been acquired either through practice or

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[88] Page, regarding the Matins clerks: "a body of singers in Paris, many of them quite youthful, and including singers expert in performing polyphony, yet with no long-term security..." Christopher Page, *The Owl and the Nightingale* (London: Dent, 1989), 144.

[89] Wright, *Music and Ceremony*, 24-5. See also, Page, *The Owl*, 144.

[90] Wright, *Music and Ceremony,* 26.

was present at the start of their singing career as source documents indicate that polyphony was most likely performed by individual singers on each voice part, with the exception of the highest ranking feasts such as Christmas and Easter. On these occasions, records indicate the possibility of multiple tenor singers.[91] It is possible that most clerics didn't learn polyphony, or didn't learn it until later in the medieval period.[92] As such, in the twelfth century, this means that polyphonic singers were limited in number, and that it was a specialized skill.

In records concerning polyphonic singers there are two singing roles identified for their specialized skills: the tenorista and the machicoti. The machicoti sings the solo lines of organum. As such, they had the ability to memorize large amounts of repertoire, make artistic decisions in performance, and to read notation. The term "machicoti" is additionally applied to singers of elaborate upper voices in other medieval and renaissance repertoires, as the skills of the machicoti could be applied to any repertoire.[93] The tenoristas were those who sang the sustained chant in tenor lines, and had the specialized skill of a singer who "would need to be sufficiently familiar with the source material to be able to hold his part without forgetting where he was within...the chant; he would need to know where to change works, and he would need to know where to breathe in relation to what was going on above him."[94] The skills of a Tenorista would additionally be applicable to copula settings, which also feature the long sustained notes of the chant melody. The musical repertoire at Notre-Dame had great

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[91] Baltzer, "The Geography," 50-54.

[92] Busse-Berger, *Medieval Music*, 112-113. See also Wright, *Music and Ceremony*, 24.

[93] John Potter and Neil Sorrell, *History of Singing* (Cambridge: Cambridge University Press, 2012), 53-54.

[94] Ibid., 54.

need for singers of both types, with significant skill through the twelfth and thirteenth centuries.

Records indicate that polyphonic singers were present at the cathedral through and after the twelfth century.[95] Margot Fassler identified polyphony settings of Adam Precentor (Adam of St. Victor), cantor of Notre Dame in the first half of the twelfth century, roughly 1107-1146.[96] Adam of St. Victor was responsible for the earliest layer of sequences for Notre-Dame cathedral, some of which are believed to have been copied into the *Magnus liber*.[97] Magister Albertus Stampensis, cantor of Notre-Dame from roughly 1146-1177 additionally contributed to the polyphonic repertoire of the cathedral, adding two or possibly three-voice conductus.[98] Léonin and Pérotin, the next figures in the musical narrative of Notre-Dame continued the polyphonic tradition at the cathedral. Léonin and Pérotin are two of the figures most lauded for their musical contributions to Notre-Dame polyphony. They were identified as musical figures by Anonymous IV who credits Léonin with the title "best composer of organa (according to what was said" and Pérotin with the title "best composer of discant."[99] The composer-poet Léonin, as identified by Wright, is first mentioned in documents as a cleric/admin at St. Benoit, one of the collegiate churches under the purview of Notre-Dame cathedral, in 1179, where

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[95] Even before this, there is a possibility that improvised polyphonic practices occurred at the cathedral. This is suggested by the improvisation techniques discussed in *Musica Enchiriadis* and *Scholia Enchiriadis*, two ninth or tenth century singing treatises. These treatises teach students how to improvise at the fifth, and octave, doubling the chant melody. However, there is no evidence to support this claim. Claude V. Palisca ed., *Musica enchiriadis: and Scolica enchiriadis,* trans. Raymond Erickson (New Haven: Yale University Press, 1995).

[96] Fassler, "Who was Adam of St. Victor?," 233-269.

[97] Ibid., 245-247.

[98] Wright, *Music and Ceremony*, 279.

[99] Yudkin, *The Music Treatise of Anonymous IV*, 39.

he would continue to serve in some capacity until his death.[100] If all the documents indicate the same figure, Léonin additionally served as an administrator at St. Victor (an abbey church and intellectual center in Paris) in 1187, and ascended to priesthood and made a Canon at Notre-Dame in 1192.[101] Anonymous IV, writing almost one hundred years after Léonin's death, is unable to attribute any settings to Léonin. Modern scholars have additionally struggled to firmly attribute settings to Leronin, due to the revision of the repertoire and the lack of records.

The dating of Pérotin's arrival at the cathedral is uncertain, but it is likely that he was present at the cathedral between 1183-1193.[102] The difficulty in identifying Pérotin at the cathedral has been the popularity of the name at the time - from 1183-1207 there are several Pérotin's active at the cathedral making the identity of Pérotin the composer difficult to pinpoint. Documents reveal a Pérotin that was made a canon in 1198, and a Pérotin became Succentor in 1207.[103] These could have been the same or separate figures at the cathedral, and perhaps not the Pérotin identified by Anonymous IV at all. The death date of Pérotin is under some dispute, but occurs in either 1238 or the 1240s.[104] Anonymous IV additionally credits Pérotin with two *quadrupla* settings (Viderunt Omnes and Sederunt Principes), two *tripla* settings (Alleluia and Nativitas), as well as a monophonic conductus (Beata Viscera), a two part conductus (Dum Sigillum),

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[100] Craig Wright, "Léoninus: Poet and Musician," *Journal of the American Musicological Society*, vol 39, No.1 (Spring 1986), 7.

[101] ibid., 9. For more on St. Victor, see Chapter 2.

[102] Wright, "Léoninus," 12-13.

[103] Wright, *Music and Ceremony*, 291. See also: Hans Tischler, "Pérotinus revisited," in *Aspects of Medieval and Renaissance Music: A Birthday Offering to Gustave Reese*, Jan LaRue, ed. (New York City: W. W. Norton, 1966): 813-14. Yvonne Rokseth, *Polyphonies du XIII siècle,* IV (Paris, 1939), 50.

[104] Wright, *Music and Ceremony*. 291. See also: Payne*, Chancellor.*

and a three part conductus (Salvatoris Hodie).[105] Because of the compositions attributed to him, Pérotin in particular has been a central figure in the history of Notre-Dame's repertoire. However, as part of the larger picture, Pérotin is only one part of the development of polyphony. When considering the history of singers and composers together, it is clear that Notre-Dame had thriving polyphonic practices through the twelfth century and beyond.

Further emphasizing the role of singers in the development of the repertoire, is evidence of continued improvisational practices at the cathedral. One example includes the writing of Anonymous IV who separately addresses the composition and singing of discant polyphony. He describes three types of discant singers:

> there are some who are plain and new; and they do as mentioned above [moving in parallel motion], except occasionally, since sometimes without even knowing it they descend or ascend in a different way to a different consonance than to a parallel one. There are certain others, who use the other method mentioned above [contrary motion], and they are discant singers. And there are certain others, who partly agree with the first group and partly with the others, etc., as will be made clear more fully below.[106]

This quote indicates that there existed discant singers who use every type of motion: parallel and contrary motion, or both; those who make mistakes; and those who move between dissonance and consonance. Described in this manner, discant singers seem to have relative freedom in creating melodic contours. These descriptions of specific types of motion also harken back to the early improvised organum practices described in the ninth century music treatises *Musica enchiriadis* and *Scolica enchiriadis*.[107]

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[105] Yudkin, *The Music Treatise of Anonymous IV*, 39. Wright, *Music and Ceremony*, 39.

[106] Yudkin, *Anonymous IV*, 66.

[107] Palisca, *Musica enchiriadis and Scolica enchiriadis*.

Printed together, *Musica* and *Scolica enchiriadis* act as manuals to teach students improvised organum including both parallel organum (featuring parallel motion at a set interval of a fourth of fifth) and contrary organum (in which harmonic motion can be parallel or contrary). While no direct links exist between the organum practices of the *enchiriadis* treatises and Anonymous IV's thirteenth-century discant descriptions, taken together, this suggests the possibility of separate or coexisting improvised singing practice occurring at or near the cathedral through at least the thirteenth century.

The most direct record of polyphonic practice in the twelfth century comes from an ordinance of Bishop Odo of Sully. Written in 1198, Sully addresses singing and behavior at the feast of Circumcision, stating the following: "Mass, along with the hours, will be celebrated in a regular fashion...the gradual [Viderunt Omnes] and Alleluia [Dies sanctificatus] will be sung in two-voice, three-voice, or four-voice organum in silk copes, and four will proceed [to the center of the choir] in Mass."[108] This ordinance indicates that, at least by the end of the twelfth century, polyphony was an established practice, particularly in the Christmas Octave, which includes the Feast of Circumcision, that any setting could be selected and performed.

The uncertainty of performance practices of polyphony and the training of singers creates space for many inquiries into how the singers participated in the development of, and recording practices of the repertoire. Information available about the training of polyphonic singers indicates proficiency in memorizing the repertoire, a high level of skill, and a well developed practice. Documentation indicates the singers of Notre-Dame were required to memorize the repertoire—a feat that took incoming singers six months

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[108] Wright, *Music and Ceremony*, 240.

to a year to accomplish.[109] The variances in rhythmic mode found in manuscript concordances suggests that singers performed different versions with each performance as a result of oral and improvisatory practices.[110] If the development is happening both on and off the page, this could indicate that temporal distance is, in the case of the pieces recorded, almost irrelevant. Polyphonic settings could have changed with each performance no matter when they were recorded depending on the singers, as will be discussed at length in multiple chapters of this dissertation. The singers' contribution to polyphonic development, as told and untold by the written sources, is a central point of investigation in this project.

A Note on Modern Ear

A final aspect of performance practice that must be considered is the issue of modern recordings and their relation to the study of medieval performance practice and sound. Given the tenuous relationship between modern performances/recording, and musicological study, one must recognize the potential trappings and assumptions that may become implicit in the study of twelfth-century polyphony. The study of performance practice in early music has been discussed at length in Daniel Leech-Wilkinson's book *The Modern Invention of Medieval Music*, and in the work of Christopher Page. Wilkinson details the reciprocal relationship between performers and scholars in the debate surrounding whether or not all the voices in a polyphonic setting

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[109] Ibid., 26. AN, LL 117 and AN, LL 125. These primary sources are from the fifteenth century, however, it stands to reason that this was a long tradition at the cathedral.

[110] Busse Berger, *Medieval Music*; Edward Roesner, "The Performance of Parisian Organum," *Early Music* 7, no.2 (1979), 174-189. Yudkin, "The Rhythm of Organum Purum." Adam Mathias, "*Clausulae* in Two Modes" presented at *The American Musicological Society Annual meeting*, San Antonio, 2018.

were sung, or if the lower voices used instrumental accompaniment.[111] Performers in the late 19th century through the 20th century made a variety of creative choices in regards to instrumentation and presentation of form, such as singing voices individually and then combining, repeating phrases/settings. However, as shown by Leech-Wilkinson, the studies of previous scholars—such as Hugo Riemann and Sir John Stainer—and live performances or recordings greatly influenced the early stages of medieval musicology. Scholars, lacking concrete evidence about performance practice, let their aesthetic tastes and appreciation of performances, influence their readings of manuscript sources and the instrumentation they claimed was in the settings.[112] This influence was the result in part of many things including what we would now consider scholarly negligence, but also due to the limitation of source material—an issue that we have seen as having many consequences through the ages. As such, any study of sound in the medieval period is not without its biases and influences.

This study is also not exempt from the influences of modern recordings and performances. Ensembles such as the Hilliard Ensemble, whose recordings of Notre-Dame polyphony have been some of the most prominent in the listening sphere, are hard to disconnect from in thinking about sound. Their recordings of settings attributed to Pérotin, included on the albums *Pérotin*, and *Pérotin and the Ars Antiqua,* are both recorded within cathedral spaces. *Pérotin and the Ars Antiqua* was recorded in

[111] The primary evidence for this being that some voice parts within the manuscripts are untexted, leading some scholars to believe that these parts would have been played on instruments. Additional evidence includes complicated runs that seemed more suited to instruments, improper texting within voice parts, and the 19th century belief in the superiority of vocal music.

[112] Daniel Leech-Wilkinson, *The Modern Invention of Medieval Music: Scholarship, Ideology, Performance* (Cambridge: Cambridge University Press, 2002),13-87. Elizabeth Randell Upton will be discussing this in her forthcoming work which examines "authenticity" in the early music revival of the late twentieth century, and how popular music influenced performance choices in early music recordings.

the chapel of Trinity College, Cambridge, from the sixteenth century, and *Pérotin* was recorded in Boxgrove Priory in Sussex from the twelfth century. Both spaces provide a natural reverberation, possibly enhanced by recording technology, that mimics some of the acoustics of the high-vaultic cathedrals of Gothic France. This makes the recordings highly compelling, and difficult not to reference while performing analysis.

One of the most influential elements of these modern recordings is the vocal quality. The high level of training within the members of the Hilliard Ensemble results in dynamic phrasing, outstanding tuning, and well supported vocal lines. This is not to devalue or undermine the possible skill levels of medieval polyphonic singers, as their training would have resulted in highly trained singers. However, the modern vocal techniques employed by the Hilliard Ensemble and others are strikingly familiar to the modern ear. Additionally, as an academic vocal group, their choices of tempo and tuning have been carefully considered as part of their performance practice.[113] Each performance, then, has been carefully stylized and performed to the utmost of their ability. It is difficult to unhear these performances, and yet the analysis below attempts to work outside of these recorded sounds, to consider each setting without bias. For one of the three main case studies, this is possible due to the lack of recording available of the setting. The other two settings, with multiple recordings available,[114] have posed a more difficult challenge. However, these performances inscribe a particular practice that is likely unrepresentative of the twelfth or thirteenth-century practice it purports to record.

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[113] Ross W. Duffin, "Just Intonation in Renaissance Theory & Practice," *Music Theory Online* 12, no. 2 (2006): 1-16.

[114] *Sederunt Principes* was recorded by the Hilliard Ensemble, and *Alleluia Dies Sanctificatus* was recorded by Red Byrd.

In discussing polyphonic musical gestures to analyze their sonic implications the recording presents a hazardous preconception of these elements due to their enhanced reverberation and close proximity to their sound source. To work around the impositions of the recordings I have chosen to discuss only rhythmic and melodic gestures and trends that can be found through significant portions of the repertoire, most of which remains unrecorded. Working from the score to discuss musical elements representative of broader occurrences enables questions that focus on what those rhythmic and melodic gestures enable sonically within the polyphonic practice. This discussion works outside musical considerations of tempo, tuning, and voice quality, as each of these elements would vary and are outside the scope of the research of this dissertation.[115] By abstracting much of my discussion of polyphony to individual elements, I aim to ignore the sound qualities of the recordings.

The impact of the cathedral as an acoustically shifting performance space under construction, the uncertainty of the practice preserved by the written practices, and the singers contribution to the development of the repertoire are the three matters of contention at the core of this dissertation. As described above, scholars of Notre-Dame polyphony have either failed to consider these subjects, or have considered them only as separate issues. However, only in considering them together can the depth of each matter, but individually and collectively be revealed. The cathedral did not just contain the singers and their practice. Just as opera and concert halls played a role in changing symphonic practices, so too did the cathedral affect liturgical practices. Surviving

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[115] Work has, however, been done by scholars and modern early music performance groups to experiment with just these factors. Leech-Wilkinson, *The Modern Invention of Medieval Music.* See also: Margaret Bent, "Impossible Authenticities" *Il Saggiatore Musicale* 8, no 1 (2001): 39-50. Elizabeth Randell Upton, "Concepts of Authenticity in Early Music and Popular Music Communities" *Ethnomusicology Review* 17 (2012).

manuscripts certainly contain many voices, but the ones most prominent are those of the scribes. But the settings the manuscripts contain were voiced and sounded by the singers. The singers themselves must have contributed to the repertoire, but how their performances and practices are contained on the manuscript page must be analyzed in context of the cathedral and their changing acoustic environment to provide yet more insight into the musical practices at Notre-Dame cathedral.

Chapter Breakdown

Throughout my dissertation I interrogate the relationship between the music, sound, cathedral, and acoustics. My dissertation primarily focuses on the years in which Notre-Dame cathedral was under construction, from 1163-1320 which includes the addition of the chantry chapels. I focus on the years from 1182 to around 1208 when the Notre-Dame chapter was performing within just the choir of the cathedral. It is during this period that a significant amount of rhythmic development and experimentation took place, as will be discussed in chapter two. In each chapter I use a different lens to reconnect the music, sound, and performance practice with the material and performance conditions that worship and polyphony took place within. I combine musical analysis in chapter one, material analysis in chapter two, acoustic testing in chapter three, and sonic analysis in chapter four to reinvestigate the development of polyphony at the turn into the thirteenth century. These analytical lenses additionally serve to analyze together the written sources, cathedral as performance space, and the practices and contributions of the singers.

In Chapter One, “Sounding Structures: A Re-analysis of Notated Musical Features,” I explore the sonic actualization of the notated music. That is, I reanalyze notated settings from W1 and F with a sound-based analysis to examine how rhythmic and textural elements could have functioned as techniques of sound production, the emission of vibrations, and sonic emphasis. I explore the sonic effects of the notated musical aspects to address questions such as: how might singers of the different rhythmic textures of organum, copula, and discant use musical features to fill the height of the vaults? Which musical features could also be used to better produce or sustain sound? In order to explore these questions, I further investigate the separation between contemporary definitions of music and sound within the coexistence of written and oral transmission, and performance practices including improvisation in the medieval period. This discussion highlights the distinction between music and sound even, or especially in the medieval period when notation is just beginning to be able to capture parts of the musical practice.

Further, in this chapter I analyze how rhythmic and textural elements could have functioned as techniques of sound production, the emission of vibrations, and/or sonic emphasis, as well as how musical elements were designed to highlight, or resound a melodic, harmonic, or rhythmic gesture, in response to the new cathedral acoustics. I have elected to analyze W1 and F because of the changes in the repertoire represented in these two manuscripts. W1, having been copied in Scotland and at an earlier date than the other manuscripts, presents an earlier iteration of the repertoire as discussed above. This is corroborated by the limited number of concordances between W1 and F. I have selected F because of the inclusivity of the Parisian repertoire found in the manuscript, which presents a later and more contemporary compilation and features a variety of genres included and changes in rhythmic modes. Specifically, I analyze *Terribilis v. Cumque Evigilasset Iacob*, *Alleluia Dies Sanctificatus*, and *Sederunt Principes* as examples of the different rhythmic genres and for their variety of textural and musical features including voice exchange, repetition, phrase length, and rhythm. My analysis is, however, informed by broader trends and features in Notre-Dame's polyphonic repertoire. With the analysis of these three polyphonic settings, I begin to address the underlying inter-materiality between space, performers, and the repertoire

To get a more holistic understanding of the materials and performance conditions through the construction of the cathedral, in Chapter Two, "Structures for Sounding: The Physical Space and Performance Requirements," I investigate how the construction history of the cathedral affected performance practice. No records from this period remain to detail the adjustments made to worship or worship practices during the construction period, however, some changes must have been made. For instance, as the construction of the choir was underway, the choir would have needed an alternative worship space. Or, during the renovations and additions to the cathedral made in the thirteenth century, singers would have needed to do something to combat the construction noise and missing walls within the choir of the cathedral. As such, I examine aspects such as the materials within the cathedral, accounting both the materials present and those absent through different stages of construction, the limited light, the addition of new sections of the cathedral as they are completed, and construction noise.

Each change and addition within the cathedral would have required some adjustment from the singers, from the chanters to polyphonic soloists, whether the new space require more volume to fill or to combat construction noises or if the missing walls or vaults required singers to move, double parts, or sing in a different rhythmic texture in order for the other chapter members to hear them. Additionally, singers and listeners in different locations within the choir of the cathedral would have had a different experience throughout construction due to their proximity to different materials. As such, in this chapter I take into consideration the different types of liturgical singing as well as the location of the singers to examine the material and performance conditions. To explore the performance conditions through the construction of the cathedral I consider the acoustic features of the materials within the cathedral, what is known of the singers and performance practice, and the variety of polyphonic settings available to them in the repertoire.

In Chapter Three, "Space Sounded: Acoustic Testing and Analysis," I analyze the acoustics of the cathedral's choir to better understand how the acoustics of just the choir may have contributed to the rhythmic development of polyphony at Notre-Dame. A significant portion of the rhythmic development in the late twelfth and early thirteenth century happened within the incomplete cathedral—approximately thirty to forty years of singing occurred in the choir, enclosed with a wooden wall. In use between 1182 to approximately 1220, the enclosed choir was the performance space of what is believed to be the premier of Pérotin's *quadrupla* settings *Viderunt Omnes* and *Sederunt Principes*. To better understand how the choir affected rhythmic development this chapter asks: what did the enclosed choir sound like? How might different rhythmic textures and melodic gestures have interacted within the space?

To examine this space, I make use of modern architectural and acoustic technologies to recreate the choir and test its acoustics. First, I digitally modelled the cathedral as it might have stood at the end of the twelfth century, using studies from art history, archival documents, and images and measurements made available from those previous studies and the cathedral. In order to analyze the acoustics of this space, I then imported this model into EASE AFMG acoustic modeling software to get measurements on acoustic features including reverberation, intimacy, envelopment, and clarity. As part of the acoustic tests, I also analyze data from sound receivers placed in different locations in the choir, including where the singers may have stood, where the bishop sat, and close to the wooden wall. It is my intention that the acoustic testing and analysis will shed light on the performance and rhythmic adjustments required of singers (as discussed in Chapter Two) to insight a new analysis of the repertoire.

Finally, in Chapter Four, “Sounding Space: Listening and Polyphony within the Choir,” I explore the aural feedback of singers and listeners in different locations and the sonic advantages and limitations of the various polyphonic textures being sung in the choir. I examine how acoustic features including the long reverberation times, poor clarity, and echo (revealed through the acoustic testing in Chapter Three) impacted polyphonic singing of organum *duplum, triplum and quadrumplum*, as well as discant and chanting. Further, I analyze how the location of the singers changes aural feedback and the listener’s perception of each genre of polyphony. My analysis in this final chapter builds upon the musical analysis from Chapter One, the material conditions outlined in Chapter Two, and the acoustic testing of Chapter Three to culminate in a conclusionary analysis. My final chapter reincorporates sound studies to explore what singing and listening within the choir might have sounded like and how different rhythmic textures would have responded within the acoustics of the choir.

Sounding Structures:
A Reanalysis of Notated Musical Features

"Is the materiality of writing a specific thing, locatable to the technologies of a particular time and place? Or may we speak of a more general "thingness" that has been writing's product across the centuries of its use?"[116] These inquiries posed by classicist Shane Butler are the broad premise of his investigation of the contents and matter of the page for ancient and medieval authors—time periods in which co-existent oral and written cultures thrive. Questions of the "thingness" of writing have been equally posed of music and musical writing (also termed notation) as inquiries of "what does this page of music notation contain and communicate?" abound in musicological scholarship explicitly and implicitly. This question is particularly pertinent in discussing the elusive rhythmic development of the twelfth century captured by thirteenth-century manuscript sources. Indeed, as musicologist Emma Dillon states: "while Notre Dame polyphony probably survived from the early decades...through oral...transmission, it comes down to us through a series of manuscripts...inscribed in new, much more prescriptive forms of notation, ones that translate (and transform) early performance traditions in important ways."[117] What, then, is the "thingness" of music and its notation and how does it relate to performance practice? To sound?

The thingness of medieval music has been transformed into modern notions and definitions of European classical music, likely far from its original form. Since the

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[116] Shane Butler, *The Mater of the Page: Essays in search of Ancient and Medieval Authors* (Madison: University of Wisconsin Press, 2011), 6.

[117] Emma Dillon, *Medieval Music Making and the Roman de Fauvel* (New York: Cambridge University Press, 2002), 2.

nineteenth century the study of medieval music has been subsumed into the modern definition of classical music, and its figures and repertoires subsumed into the progressive narrative of western classical music history.[118] The earliest medieval music scholarship discovered, transcribed, and catalogued Notre-Dame's repertoire and the sources needed to read the music's notation. This scholarship included Edward Coussemaker's work on the thirteenth-century music and music treatises, and Friedrich Ludwig's cataloguing of the thirteenth-century repertoire; identifying central source of Notre-Dame polyphony (such as Wolfenbuttel 1 and 2, and the Florence Manuscript and the lost *Magnus liber organi*); trying to build a chronology of these works and sources; and, identifying the central figures (such as the composers Léonin and Pérotin) that would become the focus of much scholarship.[119] However, in the identification and study of different genres of music found in both the manuscripts and the thirteenth-century treatises, scholars such as Ludwig, Willi Apel, and Richard Hoppin within medieval musicology, formulated a perceived linear development of rhythmic experimentation and

[118] Daniel Leech-Wilkinson, *The Modern Invention of Medieval Music: Scholarship, Ideology, Performance* (Cambridge: Cambridge University Press, 2002).

[119] Charles Edmond Henri de Coussemaker, ed., *Scriptorum de musica medii aevi*, 4 volumes (Paris, 1867/repr. Hildesheim, 1931 and 1988). Friedrich Ludwig, *Repertorium organorum recentioris et motetorum vetustissimi stili* (Halle: Niemeyer, 1910-1964), 2 volumes. Heinrich Husmann, "The Origin and Destination of the *Magnus liber* organi,'" *The Musical Quarterly* 49 (1969): 311-30. Husmann and Andres P Briner, "The Enlargement of the 'Magnus liber organi' and the Paris Churches St. Germain l'Auxerrois and Ste. Genevieve-du-Mont," *Journal of the American Musicological Society* Vol 16, No. 2 (Summer, 1963): 176-203. Hans Tischler, "The Evolution of the 'Magnus Liber Organi,'" *The Musical* Quarterly Vol. 70 No. 2 (Spring, 1984): 163-174. William G. Waite, "The Abbreviation of the *Magnus Liber*," *Journal of the American Musicological Society* 14 no. 2 (Summer 1961): 147-58. Edward Roesner, "Who 'Made' the *Magnus Liber,*" *Early Music History* 20 (2001: 227-66. Craig Wright, *Music and Ceremony at Notre Dame of Paris, 500-1500* (New York: Cambridge University Press, 1989). Hartmut Schick, "Musik wird zum Kunstwerk: Léonin und die organa des Vatikanischen Organumtraktas," in *Studien zur Musikgeschichte: Eine Festschrift für Ludwig Finscher* ed. by Annegret Laufental (Kassel: Bärenreiter, 1995), 34-43. Helmut Schmidt, "Zur Melodiebildung Léonins und Pérotins," *Zeitschrift fur Musikwissenschaft* 14 (1931-32): 129-34. Ernest Sanders "The Question of Pérotin's Oeuvre and Dates," in *Festschrift für Walter Wiora* 30, Ludwig Fischer and Christoph-Hellmut Maligne, eds. (Bärenreiter, 1966): 241-49.

musical genres.[120] In the desire to attribute and place works within a chronology, as seen particularly within the Bach and Josquin repertoires, style attributions dangerously assumed that more complex pieces were composed later than those considered to be simple.[121] Within the Notre-Dame repertoire, a similar chronological narrative developed that outlined the development from two-voice organum to the motet emerged, again assuming rhythmic complexity as evidence for dating and development.[122] These progressive narratives based on rhythmic and melodic complexity and development emerged based on teleological assumptions made about medieval music, and as a way to explain the progression of music from medieval to later time periods.

In order to ontologically understand medieval music, today's scholarship on medieval music has worked to correct early scholars' aims to place medieval music as the earliest stages of western music and to the relation of later musical forms to those of the medieval period. Page, as discussed in the introduction, examines how the study of

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[120] Friedrich Ludwig, "Beethovens Skizzen," *Göttinger Zeitung* (December 12, 1920). Friedrich Ludwig, "Die liturgischen Organa Léonins und Pérotins," in *Riemann Festschrift: Gesammelte Studien. Hugo Riemann zum sechzigsten Geburtstag überreicht von Freunden und Schülern* (Leipzig: Max Hesse Verlag, 1909), 200-213. Willi Apel, *French Secular Music of the Late Fourteenth Century* (Cambridge: Medieval Academy of America, 1950). Richard H Hoppin, *Anthology of Medieval Music* (London: W. W. Norton & Company, 1978). See also: Gilbert Reaney, *Manuscripts of polyphonic music, 11th through early 14th Century* (München-Duisburg: G. Henle Verlag, 1966). Ursula Gunther, "Problems of Dating in Ars Nova and Ars Subtilior," in *L'ars nova italiana del trecento* 4 (1978), 289-301.

[121] Richard Sherr, ed., *The Josquin Companion* (Oxford: Oxford University Press, 2000). David Fallows, *Josquin* (Turnhout: Brepols, 2009). Georg von Dadelsen, *Beiträge zur Chronologie der Werke Johann Sebastian Bach* (Trossingen, 1958). Alfred Dürr, "Zur Chronologie der Leipziger Vokalwerke J. S. Bachs," *Bach-Jahrbuch* XLIV (1957): 5-162. Gerhard Herz, ed., *Johann Sebastian Bach: Cantata No. 140 "Wachet auf, ruft uns die Stimme"* (New York, 1972), 3-50. Alfred Dürr, *Studien über die frühen kantaten Johann Sebastian Bachs. Verbesserte und erweiterte Fassung der im Jahr 1951 erschienenen Dissertation* (Wiesbaden, 1977). Arthur Mendel, "Recent Development in Bach Chronology," *The Musical Quarterly* Vol. 46, No. 3 (July ,1960): 283-300.

[122] Leo Treitler, *With Voice and Pen: Coming to Know Medieval Song and How it was Made* (New York: Oxford University Press, 2003). Edward Roesner, ed., *Ars Antiqua: Organum, Conductus, Motet* (Burlington: Ashgate, 2009). Edward Roesner "Johannes de Garlandia on *Organum in speciali,*" *Early Music History* 2 (1982): 129-160. Jeremy Yudkin "The *Copula* According to Johannes de Garlandia," *Musica Disciplina* 34 (1980): 67-84.

the medieval period is stymied by its label of "medieval," resulting in the discussion of medieval music as a building block to later time periods, incapable of being as artistic as the music of later periods.[123] Busse-Berger has shown Ludwig's foundational studies of thirteenth-century polyphony embeds a progressive narrative of medieval music.[124] That is to say that Ludwig's studies examined how thirteenth-century polyphonic practices provided a foundation for, and developed and progressed towards the masterful works of Pergolesi centuries later. In attempts to make further sense of medieval music, the ingenuity of the medieval period has also been subsumed as prequels of later classical forms such as the symphony within medieval music as seen in Andrew Kirkman's analysis and breakdown of the invention of the Cyclic Mass as a unified set of movements.[125] The prestige of later art forms and the prominence of nineteenth and twentieth-century music on the minds of many scholars has placed additional complexities and preoccupations on the study of medieval music as it came to be understood following the musical and notational advances of music from the Romantic period and later.

The concept of Western classical music, including contemporary and medieval music alike, is embroiled in post-Romantic forms and understanding of the art form, as argued by scholars such as Lawrence Kramer. The Romantic period especially (though certainly not separately from the Classical and Baroque) gave rise to prominent ideologies concerning the prestige of both the artistry of the work and the composer's

[123] Christopher Page, *Discarding Images: Reflections on Music and Culture in medieval France* (Oxford: Clarendon Press, 1993). See also: footnote 18.

[124] Anna Maria Busse Berger, *Medieval Music and the Art of Memory* (Berkeley: University of California Press, 2005).

[125] Andrew Kirkman, "The Invention of the Cyclic Mass," *Journal of the American Musicological Society 54*, no 1 (Spring 2001): 1-47.

ability to create. As Kramer has observed, classical music "in its modern form...arose with the development of European music as something to be listened to 'for itself' as art or entertainment...The music composed to be heard in this way eventually constituted a discovery that permanently altered the character and concept of music both inside and outside the European tradition."[126] Within this mode of thinking, European musical works including symphonies, operas, and medieval masses alike, became aesthetic objects that held internal logics in their melodic and harmonic design and development, which in turn held (and hold) meaning for scholars of Western art music.[127] Perhaps more importantly, writers during and following the Romantic period such as Thomas Carlyle solidified focus on the composers as "great men," and the figure whose passion and genius is captured by their works.[128] The analysis of music became an exercise in understanding the forms and structures of music as evidence of the composer's mastery and control of the medium.[129] In the view of post-Romantic musicologists such as Ludwig and Kramer, music was conceptualized and valued as a product that has "meaning," it contained the composer's "intention," and demonstrates the composer's

[126] Lawrence Kramer, *Musical Meaning: Toward a Critical History* (Berkeley: University of California Press, 2002), 1.

[127] Joseph Kerman, "How We Got into Analysis, and How to Get Out," *Critical Inquiry* 7, no 2 (Winter, 1980): 311-331. See also: Ruth Katz and Carl Dahlhaus, *Contemplating Music: Source Readings in the Aesthetics of Music* (Stuyvesant: Pendragon Press, 1987).

[128] Thomas Carlyle, *On Heroes, Hero-Worship and the Heroic in History* (London: Chapman and Hall, 1840).

[129] This is perhaps best seen in Beethoven Sketch Studies, in which the number of times a melody is sketched emphasizes Beethoven's strive for perfection or the amount of pages between sketches of the same melody demonstrates his struggle to compose the piece. See: Robert Winter, "Reconstructing Riddles: The Sources for Beethoven's *Missa Solemnis*" in *Beethoven Essays: Studies in Honor of Elliot Forbes* edited by Lewis Lockwood and Phyllis Benjamin (Cambridge: Harvard University Press, 1984), 217-250. Philip Gossett, "Beethoven's Sixth Symphony: Sketches for the First Movement," *Journal of the American Musicological Society* 27, no 2 (Summer 1974): 248-284. For sketch studies see also: Joseph Kerman, "Sketch Studies," *19th-Century Music* 6, no 2 (autumn, 1982): 174-180.

"artistry" or "genius" because of the expressive qualities made possible by the development of new musical forms and harmonic languages.

As an art object the musical text can, and it often does, then become a product that reifies and codifies the genius and intention of the composer. Examples of this can be seen in not only in sketch studies but also in studies of medieval figures such as Josquin and Machaut, or even Pérotin—all three of whom are figures that have been lauded as genius in some fashion.[130] In reifying the composer, the analysis of the musical text became an exercise in understanding the forms and structures of music as evidence of the composer's mastery and control of the medium.[131] This speaks to, as Small and Kramer examine, what constitutes a work and how its meaning is portrayed, as well as the building of a literacy around good and bad works.[132] The burden of proof, so to speak, is placed on the scholar and/or analyzer to build musical literacy through recognizing, confirming, and exemplifying the composer's process and knowledge within the unbreakable connection between composer as creator and the written text as the music text. Thus, the concept of music and its representation in the written text suggest that even when scholars purport to discuss the abstract or performed notion of music, the majority are instead discussing the musical text. As such, to discuss the

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[130] Paula Higgins, "The Apotheosis of Josquin des Prez and Other Mythologies of Musical Genius," *Journal of the American Musicological Society* 57, no 3 (Fall 2004): 443-510. Stanley Boorman, "Josquin and His Influence," *The Musical Times* 112, no 1542 (August 1971): 747-749. Jesse Rodin, "When Josquin Became Josquin," *Acta Musicologica* 81, no 1 (2009): 23-38. Machaut's "genius" is usually communicated through discussions of his control over his wide oeuvre, or his harmonic language: Gilbert Reaney, "The Ballads, Rondeaux and Virelais of Guillaume de Machaut: Melody, Rhythm and Form," *Acta Musicological* 27, no 1 (January-July 1955): 40-58. Shirley Lukitsch, "The Poetics of the 'Prologue': Machaut's Conception of the Purpose of His Art," *Medium Aevum* 52, no 2 (1983): 258-271.

[131] Jennifer Bain, "Theorizing the Cadence in the Music of Machaut," *Journal of Music Theory* 47, no 2 (2003): 325-362. Wright, *Music and Ceremony at Notre Dame of Paris,* 289-291.

[132] Christopher Small, *Musicking: The Meanings of Performing and Listening* (Hanover: Wesleyan University Press, 1998). Kramer, *Musical Meaning*.

actualization of the written product, other methods, such as sound studies, are required to connect the page to the sounded practice.

Because of the constraints and complexities surrounding the musical text, the study of music as sound examines a phenomenon that coexists in writing or notation and in the practices off the page. The constraints on the definition and the history in the study of music as a written object contributed to the rise of the new discipline of sound studies. Utilizing inter-disciplinary approaches, sound studies is especially helpful to examine material conditions, methods of production, and the experience of music which facilitates the study of music objects and phenomena—including the works understood as music and those categories of sonic phenomena not included in the musical realm such as "noise"—in relation to the physical context and circumstances in which these phenomena occur. Sound studies' apt way of dealing with technology—from devices used to produce and consume music to the acoustic technology that moderates sound in concert halls—is especially helpful to medieval studies.[133] By considering the way sound is produced, mediated, and received sound becomes an inter-material production which calls for the simultaneous consideration of sound source, physical space, and receiving bodies.[134] Sound shows us, then, that Western classical music including medieval music is not an object but a process and an event.

Using a sonic approach created by combining sounds studies, source studies, and performance practice this chapter reconstitutes the sound of Notre-Dame

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[133] Jonathan Sterne, *MP3: The Meaning of a Format* (Durham: Duke University Press, 2012). Jonathan Sterne, *The Audible Past* (Durhman: Duke University Press, 2003). Emily Thompson, *The Soundscapes of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900-1933* (Cambridge: MIT Press, 2002).

[134] Jonathan Sterne, ed., *The Sound Studies Reader* (New York: Routledge, 2012). Nina Eidsheim, *Sensing Sound: Singing and Listening as Vibrational Practice* (Durham: Duke University Press, 2015).

polyphony in W1 and F to analyze the sound indicated within the musical text. My sonic approach combines methodologies from new approaches in medieval musicology such as Emma Dillon, scholar of medieval polyphony, whose concept of supermusicality introduces the inter-material analytical methods of sound studies to the study of medieval music. The inter-material analytical methods combine the sonic analysis and material considerations of Nina Eidsheim, scholar of contemporary opera, who connects performer and space, and Shane Butler, scholar of classical oratory texts and their manuscripts, who connects the page to voice and writing process. With an inter-material approach, the music becomes inseparable from the sound as page, performer, performance, and performance space are all considered parts of the sound of the repertoire. While the issue of space does inform my analysis in this chapter, the cathedral space will be addressed in-depth in chapters two and three.

This chapter is organized into three parts: Notation, Notation and Sound, and Analysis. First, in Notation, I raise specific issues concerning the study of notation and the development of the repertoire including the limitation of sources and the involvement of singers in the development of the repertoire. The tension between notation and performance, the written and unwritten, calls into question what the notation preserves. Second, in Notation and Sound, I put sound studies into conversation with medieval musicology to reconsider the inter-materiality of sound, and the sonic information contained on the page. Reconfiguring sound as the relationship between page, performer, vibration, and the physical space enables a new sound-based analysis of the rhythmic and melodic structures of the repertoire. Finally, the analysis focuses on two elements: sound production and sonic emphasis. Sound production examines how sound is initially produced and reverberation is sustained in settings, while sonic emphasis investigates techniques for resounding or highlighting melodic or harmonic features. These two analytical focuses, sound production and sonic emphasis, investigate the connection between page, performer, and performance space.

Notation

In previous examinations, scholars such as Leo Trietler and Ernest Sanders analyzed notation as either the impetus or response to changes in rhythmic complexity by scholars such as Leo Trietler and Ernest Sanders. Notation, as evidenced in the thirteenth-century music treatises and manuscripts, was developed for an increased ability to demarcate time on the written page. The music treatises of Johannes de Garlandia, Lambertus, Franco de Cologne, Anonymous of St Emmeram, and Anonymous IV each contain changes to the notational systems they detail. As the earliest treatise in the thirteenth century, Garlandia is viewed by scholars such as Sanders and Jeremy Yudkin as the foundational treatise from which the other authors have learned, choosing to adhere to or diverge from Garlandia's writings.[135] Garlandia's treatise meticulously details the notation of the rhythmic modes of discant, particularly the perfect rhythmic modes such as mode three.[136] The later treatises, observed by

[135] Ernest Sanders, "Consonance and Rhythm in the Organum of the 12th and 13th Centuries," *Journal of the American Musicological Society* 33, no. 2 (Summer, 1980): 264-86. Willi Apel, "From St. Martial to Notre-Dame," *Journal of the American Musicological Society* 2, no. 3 (Autumn, 1949): 145-158. William Waite, "Discantus, Copula, Organum," *Journal of the American Musicological Society* 5, no. 2 (Summer, 1952): 77-87. William Waite, *The Rhythm of Twelfth-Century Polyphony* (New Haven and London, 1954). See also: Jeremy Yudkin, *The Music Treatise of Anonymous IV: A New Translation* (Hanssler-Verlag: American Institute of Musicology, 1985). Jeremy Yudkin, *De Musica Mensurata: The Anonymous of St. Emmeram* (Bloomington & Indianapolis: Indiana University Press, 1990). Christian Meyer, *Musica Plana Johannis de Garlandia* (Badeb-Baden: Editions Valentin Koerner, 1998). Roesner "Johannes de Garlandia on *Organum in speciali,*" 129-131.

[136] Sanders, "Consonance and Rhythm in the Organum," 268. Pascale Duhamel, "The Gothic Architecture of John of Garland's De Mensurabili Musica," *Musica Disciplina* 58 (2013): 29-49. Pascale Duhamel,

Yudkin, necessarily attempt to adjust notation to capture the complexities of rhythmic developments occurring through the thirteenth century. For instance, Christian Meyer notes that Franco of Cologne provides the most flexible rhythmic notations.[137] In contrast, Anonymous IV (the latest of the thirteenth-century treatises) attempts to address more recent changes by defining the proper notation of the imperfect modes, such as mode seven, used in organum.[138] Rhythmic development in the thirteenth century is further supported by the absence of imperfect modes in W1 and the presence of imperfect modes in the same polyphonic settings in F or W2.[139] The adjustments to the notational systems in each treatise indicate that notation was continuously adjusted through the thirteenth century, not in anticipation of changes in rhythmic complexity, but to address rhythmic developments that were already in practice.[140] The notational developments in treatises and manuscripts indicate that the polyphonic practices of Notre-Dame continued in flux through the twelfth and thirteenth centuries, in both aural and written practices.

The limitation of sources obscures our understanding of the polyphonic notation and performance practices of the late twelfth century. Because of the limitation of sources, the development of rhythm and knowledge of performance practice in the twelfth century is gleaned primarily from the thirteenth and fourteenth century

Polyphonie parisienne et architecture au temps de l'art gothique (1140-1240) (Bern: Peter Lang Publishing Group, 2010).

[137] Christian Meyer, *The 'Ars Musica' Attributed to Magister Lambertus/Aristoteles* trans. by Karen Desmond (Farnham: Ashgate Publishing Company, 2015), 6-80.

[138] Sanders, "Consonance and Rhythm in the Organum," 264-86.

[139] Ibid., 148.

[140] In my own readings of the treatises, this is particularly notable in the treatise of Anonymous of St. Emmeram, who adamantly demands that scholars and practitioners adhere to a strict notational system further indicating that notation was being adjusted to practices rather than the opposite.

sources—the gap in sources forces reliance on later manuscripts and writings to discuss an early practice. However, musicologists Craig Wright and Busse Berger contend that none of the remaining sources of Notre-Dame polyphony are believed to be recorded for Notre-Dame cathedral itself, nor are they copied earlier than the 1230s, as indicated by the studies of musicologist Mark Everest.[141] Compounding the issue, the limited surviving manuscripts contain evidence as to the experimental nature of polyphonic practices, as even the concordances between manuscripts often preserve different rhythmic variations of the settings to be discussed further below. The limitation of twelfth-century sources and our subsequent reliance on thirteenth-century sources to discuss previous performance and recording practices raises questions concerning the accuracy of notation and the relation between notation, rhythmic development, and performance.

Our lack of knowledge of singer participation in the development and recording practices of the repertoire provides a further uncertainty as to the relationship between notation and polyphonic practices. The uncertainty of performance practices of polyphony and the training of singers, as discussed in the previous chapter, creates space for many inquiries into how the singers participated in the development of the repertoire. Information available about the training of polyphonic singers indicates proficiency in memorizing the repertoire was the most emphasized ability. Wright's study indicates that the polyphonic singers may have been selected for specific practical qualities including reliability, punctuality, and ability to memorize the repertoire rather

[141] That is, with the exception of the flyleaves found by Gregorio Bevilacqua in Troyes 1471 from the first quarter of the thirteenth century. See: Gregorio Bevilacqua, "The Earliest Source of Notre-Dame Polyphony? A New Conductus Fragment from the Early Thirteenth Century," *Music and Letters* 97, no. 1 (2016): 1-41.

than for their singing ability.[142] Further documentation indicates the singers of Notre-Dame were required to memorize the repertoire—a feat that had to be accomplished by incoming or newly hired singers within six months to a year.[143] The variances in rhythmic mode found in manuscript concordances suggests that singers performed different versions with each performance.[144] If the development is happening both on and off the page, temporal distance between performance and notation could be irrelevant as the settings could have been changed with each performance.

The study of notation gives rise to several tensions between the written and unwritten. Previous studies of the notation in manuscript sources indicate that the development of notation is embroiled in the development of rhythmic complexity. Yet the variance of rhythm between the few surviving sources also indicates that rhythmic development likely occurred on and off the page. Considerations of performance practice raises additional complexities concerning training, memory, and improvisation as part of the performer's role in the development of the repertoire. How then, do we account for both practices? What is it that the notation records? It is to these tensions between the written and unwritten that we now turn.

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[142] Wright, *Music and Ceremony*, 24-25.

[143]Ibid., 26. AN, LL 117 and AN, LL 125. Both primary sources are from the fifteenth century, however, it stands to reason that this was a long tradition at the cathedral.

[144] Busse Berger, *Medieval Music*. Edward Roesner, "The Performance of Parisian Organum," *Early Music* 7, no. 2 (1979): 174-189. Jeremy Yudkin, "The Rhythm of Organum Purum," *The Journal of Musicology* l2, no. 4 (1983): 355-376. Adam Mathias, "*Clausulae* in Two Modes," presented at *The American Musicological Society Annual meeting*, San Antonio, 2018.

Notation and Sound: An Analytical Frame

To discuss the sound indicated by notation, performance practice and the written record must be considered together. In order to do so, there are two main issues to contend with: the coexistence of oral and written traditions and the relationship between performance and notation. Most prominent in the field is the debate on the coexistence of oral and written traditions, and how the development of notation affects both oral and written practices. The intricate use of rhythm in polyphony has led to two main points of contention: first, whether polyphonic setting needed to be performed from the manuscript, and second, dissent over the abilities of medieval singers. Musicologist Leo Treitler contends—in a widely held opinion—that, due to the increasing complexity of rhythmic notation, polyphonic settings must have been composed with prescriptive notation, requiring the manuscript for performance. Pushing back against this long-standing narrative, Anna Maria Busse Berger argues that medieval music theory treatises, such as the Vatican Organum treatise, prove that Notre-Dame polyphonic practices could have been improvised or composed, and thus, transmitted orally with the manuscripts serving as memory boosters. In support of Busse Berger's stance, I look at aspects of the development of notation in the twelfth and thirteenth centuries, in relation to the thirteenth-century medieval music treatises which continue to formalize written notation. Further support for the coexistence of oral and written practices comes from the debate as to whether manuscripts serve as a prescription for performance or a presentation of a specific performance. While scholars such as Treitler argue that rhythmic complexity requires a fixity of performance, scholars such as Busse Berger, Dillon, and Wright contend that notation presents a practice or a suggestion of a performance, one that performers could modify. In what follows, I examine aspects of these debates over transmission and notation/performance to tease out the relationship between the page and what we know about the twelfth-century practices.

To contend with the issue of oral/aural traditions let us consider, for a moment, the concept and practice of writing. Writing can be found in many different forms—from the language contained on the page, to the story as it is told by the orator, and even the thoughts designing that story. Butler, in *The Matter of the Page*, discusses writing as a reflexive process between the contents of the page and the writer's voice in poetic examples such as the *Odyssey* and Narcissus. The writer composes first in his thoughts, then in written form, but revisits and reflects on his work. A page, then, can be said to contain the writer's voice, yet it also captures the scribe's voice, the voice of tradition after the first recitation, and captures the practices and processes of the time. Furthermore, the page is the common ground between author and reader, however, "the author's page is almost never the same as the reader's page."[145] The author's page is a private space unshared with readers, as the author's page is reflective of the author's thoughts, when all that remains of the page is the geometry the author leaves behind. Butler urges us to consider the dynamic relationship between author, reader, page, and voice in written materials, as these relationships are dynamic, changing with every page and reader. It follows that we would/should consider notation with this same regard—as a form of writing and matter of the page as complex and dynamic as the sounds we purport it to portray.

The co-existence of practices occurring on and off the page, that is, oral and written practices and traditions, complicates scholars' ability to define the relationship

[145] Butler, *The Matter of the Page*, 9.

between polyphonic performers and the surviving sources. Scholars' reliance on the limited remaining materials has led to many arguments supporting a predominantly written polyphonic practice. The development and increasing use of discant and its rhythmic complexity has led scholars such as Treitler to hypothesize that Notre-Dame polyphony was likely performed from the manuscript due to the "increasing specificity in temporal duration," harmony, and voice leading.[146] Thus, the complexity of discant, in Treitler's view, would have made it impossible for singers to perform these works from memory, or as improvisation. This stance embeds three teleological assumptions: that twelfth-century notation captured in its absolute the rhythmic and melodic content; that polyphony was composed through the technology of writing; and that medieval singers were incapable of performing this level of rhythmic complexity from memory. Each of these positions assumes a fixity to the written repertoire, failing to acknowledge not only the continued development of notation but also the practices at the cathedral.

The fixity of notation, however, is not guaranteed as many studies of polyphonic notation have discussed the written technology as prescriptive or as a record of a particular performance or practice—one that is suggestive of a possible performance. The understanding of polyphonic notation as prescriptive assumes a fixity of performance. According to Treitler, "notation became prescriptive when the stylistic circumstances demanded that pieces be the same from one performance to another."[147] That circumstance is "the rise of a rhythmic conception—by the late twelfth century in practice by the late thirteenth century in theory" which includes all of Notre-Dame's

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146 Treitler, *With Voice and Pen*, 12.

147 Treitler, *With Voice and Pen*, 89. See also Charles Seeger, "Prescriptive and Descriptive Music-Writing," *The Musical Quarterly* 44, no. 1 (April 1958): 184-85.

repertoire.[148] This viewpoint additionally assumes that the purpose of the music manuscript is to record the musical work or musical text. However, alternative views argue that manuscripts recorded musical practices, acknowledging the coexistence of written and improvisatory polyphonic practices as well as the evolving performance practices of the twelfth and thirteenth centuries. In this view—shared by scholars such as Busse Berger, Dillon, Catherine Bradley, and Elizabeth Upton—notation is representative of either one idea of a performance or of a polyphonic practice, leaving space not only for a necessary margin of error present in manuscripts but also for the performer's interpretations of the repertoire, and the scribes choices in recording a performance of the repertoire.[149] Thus, while we must rely on the manuscripts available and assume the accuracy of the notation, the notated score must be considered as one presentation of an ongoing practice.

There are many indications that twelfth-century notation was far from precise, and indeed was just beginning to experiment with ligation. In his discussion of twelfth-century ligated notation, Anonymous IV notes "there were certain men who used to notate and put letters in place of notes...which can be seen in the old books above 'Viderunt Omnes.'"[150] The use of letters in place of notes, in addition to the development of ligatures through the thirteenth century, indicates that twelfth-century notation was flexible in its portrayal of pitch and rhythmic mode. Thus, while twelfth-century notation was in some ways more precise than the heightened neumes that came before, the

[148] Treitler, *With Voice and Pen,* 89.

[149] Busse Berger, *Medieval Music*. Dillon, *Medieval Music-Making*. Bradley, *Polyphony in Medieval Paris*. Elizabeth Upton, *Music and Performance in the Latter Middle Ages* (New York: Palgrave Macmillan, 2013).

[150] Yudkin, *Anonymous IV,* 55.

flexibility of this new form of ligation left much to the knowledge and interpretation of the performer.

Further, modern notions of the composition process—one man, one pen, and a sheet of paper—compounds a fixed understanding of medieval notation and the written product. Implicit in Treitler's writings on Notre-Dame polyphony is an assumption that discant in particular was composed via writing.[151] Due to the perceived strict rhythmic structures present in Notre-Dame polyphony, the intricate connection between voice parts, including rhythm, harmony, and voice exchange must have been planned on paper. His primary source of evidence is the Vatican Organum treatise, a medieval music theory treatise that records hundreds of what Treitler, and others such as Stephen Immel, interpreted to be formulas for the composition of organa. The formulas within the Vatican Organum treatise include tenor progressions, melismatic melodies without tenor progressions, counterpoint rules for multi-voiced textures, and complete organum settings. These formulas can not only be found within the *Magnus liber* repertoire, they occur frequently throughout the repertoire.[152] Much of the precision Treitler associates with Notre-Dame polyphony came from thirteenth-century notational developments. As discussed above, the music treatises of the thirteenth century continued to refine the notational system, attempting to standardize the ligation system of the perfect modes and adding a ligation system for the imperfect rhythmic modes to address the rhythmic complexity occuring in genres such as discant and the motet.[153] Thus, Treitler concluded that Notre-Dame composers utilized the formulas of the

[151] This can be read in essays by Leo Treitler from *With voice and Pen*, and in 1983 paper "Die vatikanische Organumtraktat" as discussed in Busse Berger, *Medieval Music*, p121.

[152] Stephen Immel, "The Vatican Organum Treatise Re-examined," *Early Music History* 20 (2001): 155.

[153] See footnotes 18 and 19.

Vatican Organum treatise to craft their polyphony settings, coordinating voice parts through planning and written notation.

Treitler's argument pertaining to composition and performance, however, includes the remains of nineteenth century misconceptions of the skill level of medieval singers and the "progress" of music. In nineteenth-century discourses on early music performance practice, musicologists, such as Riemann, doubted medieval singers' ability to perform both complex melismatic passages, and passages that involve complex ensemble coordination. Treitler's argument of the increased complexity of discant requiring a written record for performance evokes these same assumptions, that the medieval performer would be unable to handle this type of complexity. Treitler's stance, counters Busse Berger, speaks to teleological misunderstandings put in place by Ludwig about the progress of medieval music that were upheld by scholars including Treitler. Namely, that polyphonic settings were composed, fixed works where "every detail has been fixed in writing."[154] These positions on performance and composition fail to take into account knowledge of medieval education, the evidence of the oral transmission of the repertoire, and the concurrent improvisatory practices of the cathedral—factors taken into account by Busse Berger.

Busse Berger's re-examination of the Vatican Organum treatise places the work as part of the medieval educational and training process and thus, as part of an oral tradition. Because of the extensive nature of the Vatican Organum treatise, Busse Berger argues that the treatise was meant to be memorized, and its rules used for either performance *or* composition. She states:

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[154] Busse Berger, *Medieval Music*, 126.

> The Vatican treatise only makes sense as a text that is meant to be memorized. Otherwise it would be tedious reading, indeed. Why repeat similar "rules" and progressions again and again? The formulas in our treatise must have been easy to memorize because they are so clearly structured, both according to tenor progressions and within the melismas themselves. They cover everything from single-interval progressions to discant sections to entire organum settings. A singer who had mastered the material in this treatise would have no trouble performing or composing pieces in the style of the Magnus liber organi.[155]

The meticulous repetitive nature of the Vatican Organum treatise evokes the same memorization practices of how school boys learn grammar or arithmetic—with systematic repetition. Having learned the formulas of the Vatican Organum treatise, performers and/or composers could have compiled "their own grammars" from manuscripts, instruction, or performances from which they could improvise and create polyphony.[156] Busse Berger uses this reading of the Vatican treatise, to support her argument that Notre-Dame polyphony was transmitted orally. With these tools—a potentially extensive number of formulas for the performance of organa or discant, and the repertoire available to them—it is highly likely that improvised and composed traditions existed at the cathedral simultaneously. Thus, the manuscript page could provide a source for the performer to refresh their memory of a suggested performance from which the trained performer could easily deviate from.

The contents of the manuscript page capture a particular practice and process, as notation provides "a witness to the unwritten tradition" as well as evidence of the continuous processes of notation development and rhythmic experimentation.[157] A notated page contains a representation of sound, the performer's voices, the scribe's

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[155] Ibid., 127.

[156] Ibid., 128.

[157] Treitler, *With Voice and Pen,* 17.

voice, and the institution's practices. The rhythmic organization of discant is more structured than of organum, however, there is still little guarantee that the setting available to us now did not change between each performance. The recorded version could, as Busse Berger and Anonymous IV suggest, be an option from which to base their own performance, or something to spark their memory. Moving away from the static, music as prescriptive narrative, the text: "even when a prescriptive text, namely a music manuscript, was employed, the variance between what the performer saw and what he then produces was far greater than for any other textually derived art."[158] Thus, notation will be considered as representative—of a performance, the scribe's memory of a performance, or an ideal of the piece—rather than prescriptive in the following analysis.

If, as Butler suggests, we consider the page as a multi-dimensional object rather than flat, then we must also reconfigure "music, " what is most often understood as a written object, as "sound"—as a vibrational practice, an event, as a full body experience. In *Sensing Sound* Eidsheim breaks from previous analytical methods to examine the inter-material nature of sound. The study of music has largely been limited to what Eidsheim terms sonic reduction, which "constrain(s) our understanding of sound through previously defined referents...fixed within the parameters of pitch, durations, forms, and genres."[159] As such, our understanding of music has been defined by, and reduced to, the written score. To reconfigure sound as an inter-material, full body experience, Eidsheim examines the physicality of performing in relation to the material conditions through which the vibrations of sound travel through, bounce off, and are contained

[158] Wright, *Music and Ceremony*, 317.

[159] Eidsheim, *Sensing Sound*, 2.

within. The result of this interplay is a dynamic, ever-changing performance that must be considered *in situ,* as a change in performing body and/or voice, or space will change the resulting sound and the experience. Sound, in this configuration, is not one element, but the interaction of all bodies and materials involved.

For the performance of polyphony, it is possible to see a similar interaction of bodies and materials takes place. There are multiple systems of interaction occurring simultaneously. First, as discussed in detail above, is the relationship between the page and the performer. This interaction directly affects melodic contour, harmony, texture, and rhythm. The page first provides a suggested performance of the setting dictating pitches, texture, and rhythm for the performer to either follow or deviate from. The new performance could later be inscribed onto the page. Second, is the three-directional interaction between the performer/auralization, vibration/sound, and the space. This interaction affects rhythm and aspects of sound including sound production and sonic emphasis of specific musical features. To fully capture the sound of polyphony, these two systems must be connected. However, the limitation of information concerning the performer/performing body, the link between sound production and sonic emphasis, does not provide enough “material” with which to make the connection.

Thus, to bridge these two systems of interaction, I turn to Dillon’s concept of supermusicality. Supermusicality, is defined as “the reinvestigation of sources for sonic information such as sound production, performance practices, or the aural effect of specific compositional elements on the listener, reconnects the written page with phenomenon of sound itself, and the process of its creation.”[160] Dillon’s approach examines what evidence of a particular performance culture is contained within a

[160] Emma Dillon, *The Sense of Sound* (New York: Oxford University Press, 2012), 25.

manuscript, and resituates the evidence in its social, intellectual, and cultural context. The concept of supermusicality provides a new method for identifying and examining sonic information within manuscripts: analyzing clues within the notation and mise-en-page in relation to performance practices. Supermusicality, then, provides the methodological link between performer and page. The analysis of the interaction between page, performer, vibration, and space combining to produce my conception of sound additionally produces a new understanding of Notre-Dame polyphony—one that is based in sound and material conditions.

The concept of supermusicality will be used in the analysis below to connect the page and sound captured by the notation to conduct a sound-based analysis. A sound-based analysis considers the vibrational actualization of the notated music, and the way that the produced vibration interacts with its surrounding material conditions. Such an analysis seeks to focus on the totality of the sounded sounds, taking into consideration not only the rhythmic organization and melodic contour, but elements including the coordination between voice parts, or affordances of a different rhythmic measures in the tenor voice. In order to do so, this analysis will first identify significant musical features and structures and then analyze their sonic implications—the vibrational results of a written musical feature, tone, rhythm or vibration. The hypothesized sonic implications of each musical feature are a result of considering the musical features as a response to or practical consideration of the number of performers within the space and the amount of sound necessary to begin and continue resonance and reverberation within that space.

Because this is a sound-based analysis, the terminology that I employ below has been selected to reflect sonic concerns. As such, the analysis focuses on two sonic elements: sound production and sonic emphasis. Sound production observes the emission of vibrations, including the initial moment of auralization and music elements designed to sustain or continue vibration throughout a setting. Sonic emphasis observes musical elements designed to highlight, or resound a melodic, harmonic, or rhythmic gesture. The sonic features of sound production and sonic emphasis reframes many of the features previously discussed in scholarship to consider the production of these musical features within a physical space.

Analysis

What follows below is my own analysis, the practical application of the inter-materiality of sound found within this repertoire. I have selected settings for analysis based on their sonic features, and the variety of rhythmic organization in tandem to other musical features, such as melodic content, and phrase length. Discussed below are three settings: *Sederunt Principes, Terribilis v. Cumque Evigilasset Iacob*, and *Alleluya v. Dies Santificatus*. These settings combine organum and discant, thus presenting many possibilities in rhythmic and textural features including irregular phrase lengths, rhythmic flexibility, and shifts in rhythmic organization. Each of these elements have sonic implications with regard to sound production and resonance, to be discussed below.

Sederunt,[161] one of two quadrupla settings attributed to Pérotin, is hypothesized to have been first performed in 1199.[162] Sederunt is a Gradual for the Mass for St. Stephen, celebrated on December 26th, and is part of the Christmas octave. At the end of the twelfth century, the Christmas octave was the most special occasion in the liturgical calendar, and as such the polyphonic settings for Christmas were the most decadent.[163] Additionally, St. Stephen was the patron saint of the previous church space, of which only the portal dedicated to St Stephen survives, adding even more significance to the feast of St. Stephen at the cathedral.[164] *Sederunt* is one of the settings that was possibly performed with two tenor singers, which has implications for sound production, to be discussed below.[165] *Sederunt* is the longest setting to be analyzed, and has just two shifts in the rhythmic measure of the tenor voice, making it a significant case study in the textures of the measured upper voices and the sound production of the held tenor.

Terribilis v. Cumque Evigilaset Iacob[166] is the responsory for the consecration of the cathedral. Both a two and three voice setting of the chant survive in F—the duplum version possibly being the version created by Léonin for the Consecration Mass in 1182,

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161 Text and translation: Sederunt principes, et adversum me loquebantur: et iniqui persecunti sunt me. Adjuva me, Domine Deus meus: salvum me fac propter misericordiam tuam./ The princes sat, and spoke against me: they have persecuted me unjustly. Do thou help me, Lord my God: Save me for thy mercy's sake.

162 Wright, *Music and Ceremony*, 289. See also Mark Everist, *Polyphonic Music in Thirteenth-Century France: Aspects of Sources and Distribution* PhD diss., (Keble College Oxford, 1985), 2-3.

163 Wright, *Music and Ceremony* 237-238.

164 Marcel Aubert, *La cathédrale Notre-Dame de Paris: Notice historique et archéologique* (Paris: Firmin-Didot, 1920), 20.

165 Rebecca Baltzer, "The Geography of the Liturgy at Notre-Dame of Paris," in *Ars Antiqua: Organum, Conductus, Motet,* ed. Edward H Roesner (Burlington: Ashgate, 2009), 59-78.

166 Text: Terribilis est locus iste non est hic aliud nisi domus dei et porta caeli vere etenim dominus est in loco isto et ego nesciebam. V: Cumque evigilasset Iacob quasi de gravi som(p)no ait. vere.

and the triplum version one of many chants that were edited or reset later in the twelfth century.[167] It is possible that this new setting was created for the completion of the cathedral in 1220, though this is difficult to confirm based on available evidence.[168] It is the triplum version that is under consideration here. This setting also features shifts between rhythmic measures through both the responsory chant "Terribilis" and verse "Cumque Evigilasset Iacob," containing both sustained tenor pitches and the measured mode six in the tenor, and shifts between melismatic singing, and modes one, two, three, and six in the upper voices.

Alleluya v. Dies Sanctificatus,[169] is a duplum setting for the Christmas mass. This setting is unattributed and undated. It features a compelling use of different rhythmic measures, as well as three distinct rhythmic measures in the tenor voice, in tandem with coordinating rhythmic shifts in the upper voice part. *Alleluya v. Dies Sanctificatus* features melismatic two voice organum, and measured discant in both mode two, six, and double longs. The shifts between these different measures are abrupt and irregular, making the setting aurally exciting, and sonically interesting, as this setting moves

[167] Jennifer Bloxam "Preaching to the Choir?: Obrecht's Motet for the Dedication of a Church," in *Music and Culture in the Middle Ages and Beyond: Liturgy, Sources, Symbolism,* ed. Benjamin Brand and David J Rothenberg (Cambridge: Cambridge University Press, 2016), 266.

[168] Wright, *Music and Ceremony*, 127. Wright notes a lack of evidence pointing towards the celebration of a consecration feast, as there is no indication of the position of the feast in the calendar of the church, and posits that the location of the duplum setting was at the end of the Magnus liber, the t*emporale* in the choirbooks, and the list of feasts requiring candles and special drapes. There is no surviving documentation of a celebration of the completion of the cathedral, only of the reconsecration of the high altar in 1330.

[169] Text and translation: Dies sanctificatus illuxit nobis: Venite gentes, et adorate Dominum. Quia hodie descendit lux magna in terris/super omnem terram. Alleluya. Haec dies quam fecit Dominus: Exultemus, et laetemur in ea./ A day made holy dawns upon us; O come, all nations, and adore the Lord; for today a great light has descended upon earth/on all the earth. Alleluya. This is the day the Lord has made; let us be glad and rejoice in it.

through multiple modes of rhythmic organization. The result is shifts in levels of sound production, and thus, different effects through reverberation and resonance.

With hundreds of settings and many genres to work from, these three settings have been selected to highlight a variety of musical and sonic features that can be found throughout the polyphonic repertoire. This is not to say that they encompass all of the musical features of the polyphonic repertoire—such a feat would be difficult within the scope of this project. The analysis below will instead focus on primarily rhythmic features such as use of mode and changes in tenor measure that might correlate to broader rhythmic shifts and changes within the possible twelfth-century repertoire. These rhythmic features, I hypothesize, have implications for sound production and sonic emphasis.

The analysis below will focus on sound production and sonic emphasis as two primary sonic results of rhythmic and melodic organization in Notre-Dame polyphony. Sound production includes the analysis of musical features such as the intoned interval at the start of a setting, rhythmic organizations that affect phrase length, and the rhythmic measure of the tenor voice. Sonic emphasis can be found in musical features such as repetition of intervals or gestures, some rhythmic organizations, and the textural aspect of voice exchange. Each of these notated musical elements are examined for their sonic implications, that is, the vibrational, or perceived, results of a written musical feature.

Sound Production

Sound production, I hypothesize, is the most important sonic implication of the polyphonic repertoire. In discussions of the rhythmic experimentation found throughout the Notre-Dame repertoire, from the florid melismas of organum to the stricter measure of discant, sound production is always under the surface. The emission of vibrations within space and the music elements designed to sustain or continue vibration, sound production is required to fill the cathedral space through elements such as intonation, phrase length, and tenor measure. Intoning the setting through a held note at the start of the setting, first begins the resonance within the space. Then, rhythmic structures and phrase length continues sound production by sustaining and extending melodic lines. Underneath it all, the tenor voice provides an almost constant source of sound, sustaining the chant, and providing the sonic foundation of the setting by holding a sustained tone or with the more active reiteration of sound in discant measure. The structures under consideration here are by no means the full extent of these characteristics, but are those that are prominent throughout the repertoire. In addition, many of the gestures discussed in sound production will have additional implications for sonic emphasis. While these attributes will be discussed separately, I do not view these two features as unconnected, and have instead chosen to later build upon sound production in the discussion of sonic emphasis. In what follows, I examine intonation, phrase length, and tenor measure and how they might have been used for sound production.

Intoning the Setting

At the start of many polyphonic settings—including *Sederunt* and *Terribilis*—is a characteristic similar in some ways to chant settings: an opening pitch to intone the setting. “Intonation” in chant practice is defined as: chanting on a repeated pitch, the opening note sung by a soloist before the choir enters, or the tuning of the pitches.[170] While not precisely the same practice, intonation in the polyphonic practice refers to the held tone[171]—usually notated as a double long—sung by all the polyphonic voices at the opening each section of the setting serves much the same purpose as that of the soloist's opening tones to the choir. The intoned sonority of the polyphonic setting establishes the opening interval, and the singer's agreement of this interval for the setting to come. Additionally, just as intoning the chant serves to increase sound production, so too does the intoning of the polyphonic setting. Intoning the polyphonic setting, I argue, function to initiate sound production and create resonance.

The held pitch to intone the setting also serves the sonic purpose of initiating resonance within the space. In both *Sederunt* and *Terribilis*, the opening of the setting and the verse being with this intonation (see figure 1.1 and 1.2). Each section of the *Alleluya* is also intoned, with the verse "Di-" providing an example of a second intonation technique in which neighbor tone motion further emphasizes the intoned interval, with the third note of the pattern acting as the held tone (see figure 1.31). Establishing resonance in the space is particularly important at the beginning of the setting, when there is either no previous sound, or, perhaps, the sound of only a soloist singing. The sustained tone, with two, three, or four voices, produces a burst of sound and is held for a long enough duration to create resonance within the space. With the large volume of the space, and an equally large reverberation time, the amount of sustained sound produced by the double long is necessary to fill the space. The duration of this tone, the

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[170] Richard L. Crocker, *An Introduction to Gregorian Chant* (New Haven: Yale University Press, 2000), 235.

[171] Here being used in place of pitch, as a term that is less restricted to what is written on the score as, depending on the tuning and reliability of the singers, the recorded "pitch" is only relative. Tone, despite its connection to the singing voice, is less restricted to the staff and the notion of exact tuning.

longest in upper voices of the setting with possible exception of the final tone, sets apart the function of this tone as a strong source of sound production.

Figure 1.1, Intonation of response and verse of *Sederunt*

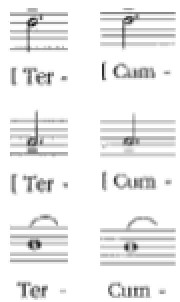

Figure 1.2, Intonation of response and verse of *Terribilis*

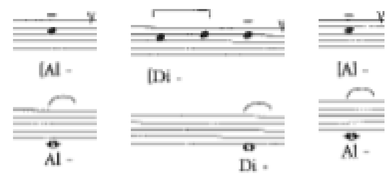

Figure 1.3, Intonation of the “Alleluya,” verse, and closing “Alleluya”

The practice of intoning the polyphonic setting can be found throughout the repertoire. Of the opening 144 folios of F, fewer than ten settings, including the verse, open with a note value shorter than a perfect long, while the majority either begin or move to a double long. The frequent occurrence of the intonation tone indicates that this technique is effective in its many functions as a tuning opportunity for the singers and as sound production within the space. Intoning the polyphonic setting with a double long in particular creates resonance within the space, providing a sonic foundation for the setting to sustain and build upon.

Phrase Length

With resonance begun in the space by the intonation element, other musical features are designed to then sustain sound and resonance. One technique for extending or altering sound production is phrase length. Phrase length, the variable amount of perfections[172] coordinated with rests in all voices, is predominantly determined by the utilization and organization of the rhythmic modes to create coordination or contrast among the voices. Homorhythmic sections often result in clear and regular phrase lengths, while more contrapuntal sections can extend or alter phrase length. In both rhythmic textures, however, change in phrase length can suddenly or gradually increase or reduce the amount of sound production.

The complication in discussing phrase length is that it could very well have been altered and shifted far more often than the score indicates. Phrase length is one musical feature that could easily be altered in improvised polyphonic performances—either through intentional use of contrapuntal rhythms or through error. The performer's knowledge of rhythmic formulas, described above, not to mention the rhythmic experimentation within the cathedral, would enable and encourage rhythmic complexity and the use of modal variety. As such, singers could have been relatively free to use shorter or longer phrases, the alteration of which phrase has a direct impact on sound production as short phrases could produce more volume, while extended phrases can result in prolonged sound production.

Shorter phrases, found in all three settings, allow singers to settle into the rhythmic mode of the opening of the setting, while establishing a level of sound

[172] A perfection is a rhythmic duration of three breves often notated in modern notation as a dote quarter note

production. For instance, “Terribilis” opens with five phrases of seven perfections*,* while the verse, “Cumque” also features primarily short phrases but less consistent in length. The repetition of short, or similar phrase lengths, results in a sonic consistency in the level of sound production. Changes in phrase length then increase or decrease sound production. The interjection of a long phrase, extends sound production and building to the change to “que.” Short phrases in both the opening and verse of *Terribilis* are first designated by rests duration of a perfect long, and transition into short phrases that are separated by rests of only a breve in the discant sections. The short phrases designated by rests of perfect longs give emphasis to the starting and ending tones of these short phrases, while also serving to produce small bursts of sound production. Regularity of short phrases, and the consistency of sustained sound makes the extension of phrase length prominent changes in sound production.

Establishing a regular phrase length additionally establishes a consistent level of sound production that can then be sustained or increased. *Sederunt* begins with only three iterations of short phrases, the first two with seven perfections, the third with five perfections. The unified short phrases of the opening, however, are quickly replaced with long phrases with smaller exchanged units within, as seen at perfection 26 (to be discussed below). The phrase length more than doubles as the next unison rest doesn’t occur until perfection 47. At this phrase (starting at perfection 26) the function of phrase length and the concluding rest changes. Rests lasting a perfect long in duration, notated as a dotted quarter, become demarcations of new or renewed moments of voice exchange, occuring at perfections 25, 47, 69, 93 (except for the duplum voice), 149, 161, 173, and 185. The extension of phrase length prolongs sound production by creating longer and more continuous phrases.

A further example can be found in *Terribilis*, in which more contrapuntal rhythmic design is used to double phrase length. The singing of “somp-no” contains the final shift into a discant clausula, and as such, a change in the rhythmic measure of the tenor voice. Matching the organization of previous discant sections in the setting, the first three units of “somp” have structured, unisons rests, but already two length of phrases: four and eight longs in duration. Beginning at long 171, first the triplum, then duplum sing through the rest in the other voice part to create an eight long phrase (see figure 1.4). In this passage, the tenor also rests after every perfect long, placing its rest just before, and lasting through, the staggered rests in the upper voice for the first two iterations. At long 179, the rhythmic organization of the duplum and triplum change, alternating sung units of four and six longs per unit above the tenor, which continues to rest every three perfect longs. This changes the resting organization staggering individual voice and unison rests between all three voices to continue the extended phrase length.

Figure 1.4 Musical excerpt, perfections 155-184, "Somp-" from *Terribilis*

The rhythmic organization of this section sonically plays with phrase length, emphasis, and sound production. The frequent breaks in the tenor line stop the most consistently sustained sound in the texture: the perfect longs in the tenor voice, disrupting sound production. Here, it is the extended phrase lengths of the upper voices that fill the gap, to continue constant sound, and thus, resonance. The extension of phrase length through contrapuntal rhythmic organization sustains sound production within the space by reducing the number of unified rests, and continuing sound.

The alteration of phrase length can also be seen as one indication of rhythmic experimentation. For instance, in "Adiuva" rhythmic experimentation and alteration of phrase length begins at perfection 58. The combination of modes in the upper voices results in staggered rests between the quadruplum and two other voices seen below in figure 1.5. The rest at perfection 71, however, is deceptive as the following unit is additionally part of the phrase, indicated by the exact repetition of material beginning at perfection 76. The phrase length of this section is almost double the previous phrases, while still toying with the ear in the small units shared by the duplum and triplum. Following this final coordinated phrase in the three upper voices, phrase length in the verse setting becomes more variable, rarely sticking to a particular pattern—seemingly experimenting with the established gesture and contours.

Figure 1.5 Musical excerpt "Adive me Domine" in *Sederunt*

The organized phrase lengths of the opening, however, almost immediately moving into areas of rhythmic experimentation. For instance, at perfection 130 the upper voices use such contrapuntal rhythmic organization that the next unison rest doesn't occur until 173. This is perhaps because this section features a high degree of rapid voice exchange but inconsistent exchange. In fact, the inconsistency in exchange duration could be read as singers improvising to mimic the earlier voice exchange, yet unsure of what gesture is being exchanged. The phrase length certainly reflects a desire to shift the texture of the setting to something less structured than the opening of the verse, experimenting with texture and rhythm yet resulting in erratic phrase length.

Whether the gradual shift in phrase length at the opening of "Adiuva" or the rapid alternation of long and short phrases, phrase length varies sound production through not only the length but use of rests at the end of phrases. Phrases that end with a perfect long produce less sound but create a more distinct separation of phrases.

However, phrases ending in the breve provide less break in sound production and continue the motion of the melodic line between phrases. Combining and alternating between short and long phrases allow singers to use either short bursts of sound, or more prolonged passages as necessary or desired for different levels of sound production.

Tenor Measure

The measure of the tenor voice, I posit, is the most significant technique for sustaining or increasing sound production throughout a setting. Settings performed for the most important feasts of the year, such as Christmas or Easter, Baltzer and Wright indicate, were possibly performed by two or more tenor singers, allowing for a constant source of sound production.[173] The need for sound production from the tenor voice increases in two-voice settings, which have fewer singers and require active sound production from both voices to fill the space. No matter the number of voices, the tenor voice can use either a held tenor, which sustains tones for at least a double long, or a measured tenor. While the held tenor provides an almost constant source of sound and an aural background, the measured tenor produces active, rearticulation of tones in the setting. Thus, in using different tenor measures, singers could increase, sustain, or decrease sound production within the setting.

Each of the three settings features the held tenor pitch: *Sederunt* uses a held tenor pitch for almost all of the setting, while *Alleluya* and *Terribilis* uses this measure only in some sections. In all three, the held tenor voice provides an aural background, with which the upper voices interact. Additionally, in *Alleluya* and *Terribilis* the held tenor

173 Baltzer, “The Geography of the Liturgy.” Wright, *Music and Ceremony*.

acts as the most prominent source of sound in organa sections—it sustains sound production in sections in which the rhythmic measure of fast moving florid melismas of the upper voice dies within the space quickly. The held tenor, in all cases, sets itself apart from the texture of the setting, providing a pitch center, and a constant source of sound. This measure of tenor, however, has some practical limitations.

Held tenor tones are only sustained if they have more than one singer or give the singer enough room to breathe regularly. Even the most talented singers have to breathe at some point. As such, tones would have been interrupted for breathing or would need to change tones with enough frequency to facilitate breathing. *Sederunt,* performed in the Christmas octave, would likely have had two tenor singers. If the recorded lengths of pitch duration in the manuscripts are accurate, the length of the sustained tone in *Sederunt* suggests that there were two tenor singers. The very first tenor pitch of *Sederunt* requires the singer to sustain the pitch for one hundred and sixteen longs. *Alleluya*, however, seems to be designed for only two signers. The tenor pitch of the opening "Alleluya," the shortest section of the setting, changes tones each syllable. This is notated in the Roesner edition as roughly every ten longs for the shift to "le" and "lu," and slightly longer for the two notes concluding "ya."[174] In "Dies Sanctificatus," the sustained tones have similarly short durations, enabling well supported singing. Thus, for a held tenor to truly be held, the proper structuring of regular rests or multiple singers must be involved. With little knowledge of this aspect of performance practice, it is unconfirmable as to what extent this was true. What can be

[174] Edward H Roesner, ed., *Le Magnus liber organi de Notre-Dame de Paris* III (Monaco: Editions de l'Oiseau-Lyre, 2001), 15.

considered is how the shifts in tenor measure affect sound production, and what affordances each type of measure produces in each setting.

The held tenor in *Sederunt* provides a sonic foundation and sustains sound production. *Sederunt*, compared to other settings within F and W1, is one of the longest polyphonic settings available in the Notre-Dame repertoire. This perhaps makes *Sederunt* exceptional in the function of the held tenor, as all of "Sederunt" and 478 perfections of "Adiuva Me Domine" are sung above the held tenor voice. There are, however, a number of possible reasons for this. First, with three upper voices in the setting, having a sustained tenor throughout the setting leaves room for the upper voices to display their intricate rhythmic and melodic features. Second, with said rhythmic and melodic activity of the upper voices, the tenor necessarily provides the only constant sound throughout the setting, providing a strong aural background to both anchor the upper voices and to supply a constant source of sound production. Third, and perhaps more importantly, with two tenor singers the held tenor can more practically be sustained throughout the setting. Having two singers allows for staggered breathing, and therefore the possibility of a consistently held tenor. With the consistency and sustained sound production of the held tenor, the changes in tenor measure are an abrupt surprise at the end of the verse.

The two shifts of tenor measure result in a significant change in sound production. The first shift into the measured tenor occurs seemingly out of nowhere, not designated by a change in syllable as it concludes "-ne" of "domine". The second shift into a measured tenor occurs at the syllable shift at the "de" of "deus" moving from mode five to all double longs for "salvum me fac...misericordi(am)," the concluding plea for salvation. Both rhythmic shifts allow the tenor to move through the chant melody at an accelerated pace, a possible necessity following the long held tones throughout the setting that must conclude the chant clausulae. However, this is not entirely the reason, as the shift to discant is interrupted by a held tone in the tenor at perfection 520, and mode five again slowed to all double longs for the declamation of "salvum" at perfection 577, indicating that the shifts in measure are not entirely due to the need to move through the chant. Rather, these shifts demonstrate using changes in tenor measure to add sonic complexity and the active rearticulation of tones that occurs with a measured tenor. The change of tenor measure sonically sets apart the end of the setting from that which came before, with the measured tenor increasing sound production within the space.

The measured tenor as increase of sound production is perhaps best seen in *Alleluya*. Limited to the sound production of only two singers, the shifts in tenor measure throughout *Alleluya* simultaneously increase sound production and declaim the text. Both the opening and closing "Alleluya" contain only held tones in the tenor voice, to leave the duplum rhythmically and melodically free, preserving the fluidity of the organa *Alleluya*. The verse "Dies Sanctificatus," however, moves between measured and held tones fourteen times (see table 1.1), emphasizing the multiple functions of the shift in tenor measure as a tool for declamation and as sound production. The shifts are fluid between the held and measured tenor, varying phrase lengths between the shifts, and highlighting the use of the measured tenor as a change in aural complexity and a difference in sound production. The sections of the measured tenor alternates between mode 5 and all double longs, with the exception of the insertion of one section measured in mode 2. Each rhythmic shift changes the level of sound production.

Table 1.1 Rhythmic Shifts in “Dies Sanctificatus”

Perfection number (approximate)	Rhythmic Measure	Syllable change
1) Perfection 18	Mode 5	None
2) Perfection 31	Held	None
3) Perfection 35	Double Longs	“Sanc-”
4) Perfection 57	Held	“-xit”
5) Perfection 61	Mode 2	“no-”
6) Perfection 86	Held	None,
7) Perfection 95	Mode 5	“ve-”
8) Perfection 111	Held	None,
9) Perfection 134	Double Longs	“et”
10) Perfection 156	Held	None
11) Perfection 166	Double Longs with perfect long	“ho-”
12) Perfection 189	Held	None
13) Perfection 207	Mode 5	“lux”
14) Perfection 261	Held	None

The frequent use of a measured tenor voice, I hypothesize, suggests that the increased sound production of discant clausulae was necessary to sustain sound. In contrast with the use of the held tenor, the use of mode 5 and double longs produces active rearticulation of tones. The sections of mode 5 often see the use of shorter phrase lengths, giving the tenor singer plenty of room to breathe, while also taking advantage of the longer sustained quality of the perfect long. Singing all double longs achieves much the same effect, but doubled in length creating more continuation of sound. As such, the measured tenor results in two voices of active sound production. Having these bursts of rhythmic activity breaks up the texture and enlivens the space by increasing sound production after sections of held tenor and rhythmically loose duplum voice.

Similar to *Alleluya*, the measured tenor is also employed in the three-voice *Terribilis* to increase and sustain sound production. However, *Terribilis* features changes in the tenor measure in all parts of the setting, rather than being limited to just the verse. The held tenor, similar to *Sederunt,* provides the aural background and stable sound source for the rhythmic variance and intricate voice exchange in the upper voices.[175] Throughout the setting, the measured tenor in many instances allows for the quick and clear declamation of the text, while also providing yet another shift in rhythmic texture and the increase of sound production. The shifts in and out of these tenor measures result in different amounts of sound production, with the measured tenor providing an increase of sound.

The rhythmic shifts that occur in the singing of “Terribilis” and “Cumque Evigilasset Iacob” function as declamation and unified, sustained sound production. The first rhythmic shift of *Terribilis* consists of only sixteen perfections, and encapsulates the syllable changes of “(Ter)-ri-bi-lis est.” Each syllable of “-ri-bi-lis” is declaimed prominently by all three voices, with the tenor in mode five, and the duplum and triplum voices coordinating with imperfect or perfect longs. The tenor’s rhythmic shifts during

[175] The discussion of the voice exchange of this section is discussed below.

“Cumque Evigilaset” have much the same features as the shifts in “Terribilis”—the tenor sings in mode five, with the duplum and triplum voice singing homorhythmically in mode one, coordinating with the tenor voice on the syllable changes with imperfect or perfect longs to declaim the text “evigilasset Ia-.” The tenor’s shift back into a held measure at perfection 90, however, does not occur for another fifteen perfections following the declamation, prolonging the combination of mode five and mode one in upper voices. At each moment of declamation, the simultaneous and consistent use of sustained tones in all the voice parts and the shift of the tenor voice into mode five would result in increased sound production.

In comparing all three settings, one question that arises is how the number of voice parts affects the use and combination of rhythmic measure. This is particularly apparent when comparing *Sederunt* with *Alleluya v. Dies Sanctificatus.* “Dies Sanctificatus” has a significant amount of sonic experimentation. While *Sederunt* features the majority of its rhythmic and sonic experimentation in the upper voices, “Dies Sanctificatus” features frequent rhythmic shifts in all voice parts. *Sederunt*, possibly performed with two or more tenor singers, likely doesn’t require as many rhythmic shifts into discant, as the multiple voices will produce more sound. A setting with only two voices, particularly with the less structured rhythmic measure above a held tenor voice, would produce far less sound and thus resonance causing the sound to die quickly within the space. The shift into a measured tenor might be a necessary measure for sound production.

Sonic Emphasis

To enliven sound production, sonic emphasis highlights, features, and/or resounds melodic tones, intervals, or contours. One of the most prominent techniques for both melodic and harmonic sonic emphasis is repetition. Repetition can occur through multiple types of rhythmic organization such as homorhythm, more contrapuntal rhythmic coordination, or voice exchange. Homorhythm allows for unobscured repetition of tones and intervals. Contrapuntal rhythmic coordination is the most obscure technique for sonic emphasis, however, it does enable the emphasis and resounding of melodic gestures. Voice exchange is a textural quality that highlights exact repetition of melodic gestures. The analysis in this section relies more heavily on the score than that of sound production, however, the sonic effects included could be accomplished by well-trained and/or experienced performers, enabled by both established improvisation practices and the formulas of the Vatican organum Treatise. Below is an analysis of a sample of musical gestures and their sonic emphasis.

Emphasis of Melodic Contours and Gestures

With sound established within the cathedral, techniques for sonic emphasis can then be employed to create aural complexity and to sustain or emphasize the sounds gestures or contours. The emphasis of melodic contours or gestures occurs through different types of rhythmic organization and through repetition or, more prominently, through voice exchange. Voice exchange, the exact exchange of melodic units between voice parts, is one of the most intricate aspects of many polyphonic settings, as all of the voices can interchange throughout the setting. Repetition of contours and gestures is a built-in feature of voice exchange, but additionally occurs in sections of homorhythm or contrapuntal organization. I would like to propose that repetition is not just a compositional feature, but rather a sonic technique to reiterate, emphasize, and sustain a particular sound within the cathedral space.

The exchange of small, “balanced” units of sound found throughout “Sederunt” serve to reiterate and resound the gestures.[176] There are two exchanged gestures within the opening “Se” section. Gesture one, seen in figure 1.6, consists of one full iteration of the mode three rhythmic structure (perfect long, imperfect long, breve, imperfect long), with four repeating pitches falling to the lower neighbor tone. Gesture one is first exchanged between the duplum and triplum, before passing to the duplum and quadruplum voice, to repeat a total of six times. Gesture two elaborates the lower neighbor motion of gesture one, expanding the phrase to twelve perfection (see figure 1.7). Gestures one and two emphasize two melodic gestures through voice exchanges, keeping the sounding of the gestures alive through repetition, a tactic that can be found throughout the repertoire. These same types of rhythmic structures will also later be discussed for their prominent emphasis of repeated intervals.

Figure 1.6 *Sederunt*, Gesture One

Figure 1.7, *Sederunt*, Gesture Two

[176] Wright, *Music and Ceremony*, 289.

Sonic emphasis can also be sustained through repeated iterations of a melodic contour. In the opening “Ad-” there are two units: one that is a repeated gesture and a second in which each voice has a different melodic gesture. The unit highlighted in figure 1.8 repeats in three exact iterations at the opening. In between the repetition of the unit, each voice emphasizes a melodic contour rather than another exact gesture.

Figure 1.8, the second and third iteration of the unit in “Ad-” *Sederunt*

In all three iterations, the quadruplum focuses primarily on the descending motion from the repeated tone to its lower fifth, though each iteration differs. The duplum provides contrary motion in both the first two iterations of the gesture before matching the quadruplum’s descending motion at the end of the phrase. The triplum primarily emphasizes neighbor motion in the first two iterations. After the third iteration of the repeated gesture (seen above under 3), the duplum and triplum voices exchange motion with neighortone motion now in the duplum voice and the triplum voice emphasizing ascending motion. The alternation of repeated gesture and similar contour is another melodic organization possible within a primarily improvised polyphonic performance, particularly as this occurs early in the verse setting as a prominent aural feature. Sonically, the repetition emphasizes melodic contours and repeated gesture by resounding, and thus sustaining the gesture and contours.

Similarly, the opening of “Terribilis” features the exchange of small repeated units of sound that feature and emphasize melodic contours. There are three such gestures in the opening section. The first gesture is introduced following the intonation by the triplum voice and consists of an ascending fourth in mode three. The second gesture occurs simultaneously, and consists of a perfect long, descending breves falling to the lower fifth sustained with a perfect long. These gestures are exchanged twice between the duplum and triplum in almost exact repetitions as seen in figure 1.9.

Figure 1.9 Music excerpt, perfections 1-10, *Terribilis*

The sonic emphasis created by the exchange of these two gestures is twofold: the immediate repetition of the melodic gestures emphasizes the contour, and the exchange between the voices additionally emphasizes the intervals. Through voice exchange, the intoning interval is repeated multiple times, exchanged through immediate leaps in both voice parts, then ascending/descending motion causes the exchange of the same tones to happen every two longs.

To further emphasize the melodic contour presented in the gestures, both are then modified and used in various forms throughout “Terribilis.” The falling fourth in gesture two gets rhythmically modified to mode three, as can be found in the duplum voice at perfection 12. We can also see an additional alteration of gestures one and two in the triplum voice at perfection 29. In this iteration, the melody of gesture one is changed, while the rhythm of gesture two is altered. Gesture one, rather than rising to the upper fourth on the perfect long, in this iteration the gesture falls to the lower neighbor. Gesture two, which follows, repeats the top pitches, altering the rhythmic organization, and extending the gesture. Both the exact and modified forms of the repeated gestures of “Terribilis” emphasize melodic gestures—one through repetition and the other through phrase length.

The alteration of texture is particularly efficient for the sonic emphasis of melody. Seen at the end of *Terribilis* in the final word “a-it”, this moment is the most aurally prominent moments of voice exchange. What distinguishes this moment is that this passage does not exchange exact gestures. This section behaves more like hocketing of long sections of melody. Above a sustained tenor, the duplum sings while the triplum rests, joining the duplum on the final pitch of the phrase. The triplum then sings a new gesture, as does the duplum in the next gesture. This moment of voice exchange is not about intricacy, but about presentation of these melodic gestures, and of the singers themselves. The thin texture, and reduction of sound places all the sonic emphasis on each individual gesture.

Tone or Interval Emphasis

Emphasis of a tone or interval within voice exchange and melodic contours could perhaps be considered an overly common attribute to consider. Yet in the three settings under consideration here, there are significant moments of repetition to produce consistent reiterations to sustain and emphasize a particular tone and interval, suggesting that it is worth reconsidering. Emphasis of a tone or interval is possible through many rhythmic organizations, however, the most prominent moments are found within unobscured rhythmic structures such as homorhythm, the use of short melodic units (a small number of perfections) of sound, repetition, or any combination thereof. Examples of both can be found in *Sederunt*, and *Terribilis*. It is difficult to draw a clear division between the emphasis of tones and the emphasis of melodic gestures, as both are intricately intertwined.

The predominantly homorhythmic texture of the verse "Cumque" in *Terribilis* highlights the terminal unison in each phrase. Following the intonation, the first four perfections of the duplum and triplum voice descend a fifth and ascend a fourth to come together at the unison to end the unit (see figure 1.10). The terminal unison is reiterated in the next three phrases, reached through contrary motion in all three iterations, with each unison preceding a rest in both voices. As the ultimate pitch in the phrases, it is this pitch that would sustain in the vaults through the resets, giving sonic emphasis not only during its initial sounding, but also afterwards.

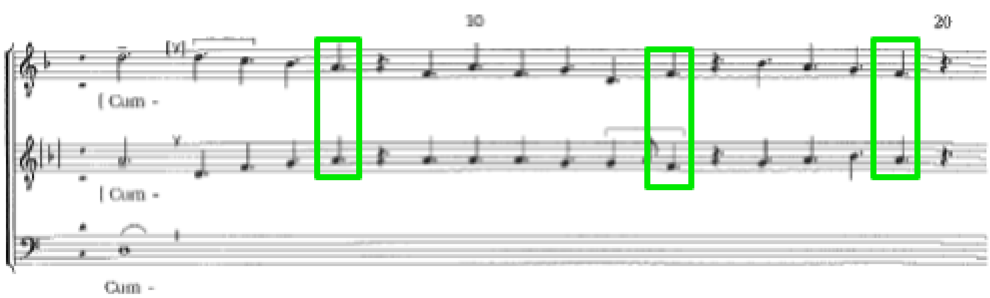

Figure 1.10 Musical excerpt, perfections 1-20 *Terribilis* verse

The sonic emphasis of the same tone is maintained through repetition and voice exchange following the shift in rhythmic organization. Moving into the shift in texture at perfection 62, there is one moment in each voice part that defies the homorhythmic organization, resulting in the emphasis of the tone. In the phrase that begins at perfection 39, the duplum voice is the first to deviate, extending the phrase through the rest of the triplum voice to descend to and resound the final tone of the triplum (see figure 1.11). The triplum voice then returns the gesture in the next phrase, singing through the duplum's rest to repeat the dulplum's phrase ending tone. Through voice exchange, the same tone is reiterated, further emphasizing the tone through repetition. Repetition in this moment sustains the sound of that phrase and tone, but the rest in one voice places additional emphasis on the pitch, as it is suddenly the only sounding tone in the upper voices.

Figure 1.11 Musical excerpt, perfections 41-51, *Terribilis* verse

In contrast, the variety of rhythmic variance in both the duplum and tenor voice of *Alleluya v. Dies Sanctificatus*, singing unison or octave pitches anchor the two voice parts together through sonic emphasis of a tone coordinating the beginnings and ends of many phrases. The sonic emphasis of the unison or octave occurs in all sections of the setting: the octave is first intoned at the start of "Alleluya" and the unison is used as the terminal interval. The verse "Dies Sanctificatus" continues the emphasis of these tones. "Di" is intoned and concluded with an octave. In the sections of measured tenor the use of octave and unison is frequent, with many phrases beginning or ending with an octave or unison. For instance, the second, third, fourth, fifth, and sixth shifts into a measured tenor (items 3, 5, 7, 9, and 11 in table 1.1) all begin with an octave, with the third shift ending with an octave and the fourth shift ending in a unison. Thus, sonic emphasis at the beginnings and endings of phrases accentuates not only the tones, but also shifts in measure.

The rhythmic organization of *Sederunt* allows for prolonged repetition and emphasis of the same interval through the long sections of the setting. The small, repeated gestures in "Se-" additionally create the frequent reiteration of the same interval in all three upper voices (see figure 1.12). The emphasis of the interval begins with the intoning of the setting and the sounding of the perfect fifth with the lower tenor octave. This same interval is then sustained with varying frequency of resounding throughout the singing of "Se." The opening twenty perfections see the least amount of repetition of the interval, yet even here the open fifth is resounded at the beginning and end of every phrase. In rhythmic mode three, this places the repeated interval on the longest possible rhythmic values to sustain the interval and create even more emphasis.

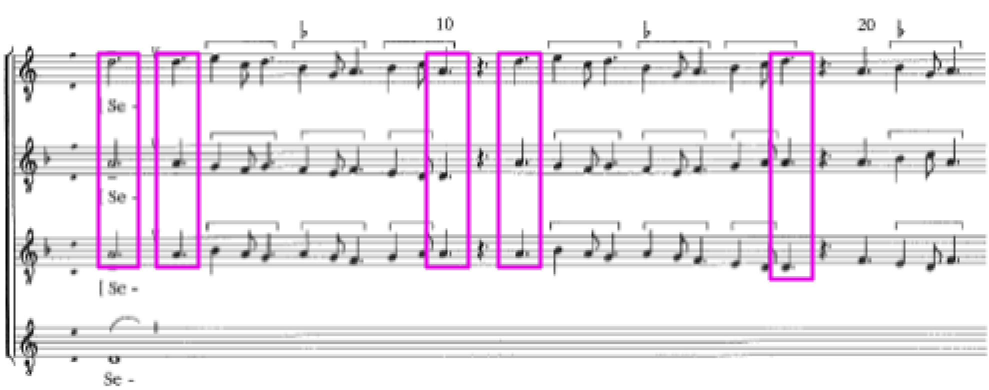

Figure 1.12 Musical excerpt, perfections 1-22, *Sederunt*

The structured rhythmic organization in the opening of *Sederunt* enables later sections to then build upon the repetition and resounding that has already occurred. At both perfection 26 and 48, the interval is resounded three out of four intervals, due to the primary use of neighbor tone motion. At perfection 48, the duplum and quadruplum voices follow the same rhythmic structure, with units of four repeated tones and the lower neighbor seen below in figure 1.13. This leaves the tripulm free to embellish their melodic line to provide a sense of motion, moving between lower and upper neighbor tones but still coordinating the longs with the duplum and quadruplum. Even with the short moving tones, the frequency of repetition in passages such as these would not be obscured, producing very prominent sonic emphasis of this interval.

Figure 1.13 Musical excerpt, perfections 48-61, *Sederunt*

While moments of this frequent and consistent sonic emphasis of a tone or interval can be interpreted as the result of strict composition, many of these moments of emphasis could very well be the result of improvisation. Passages such as these rely only on each singer utilizing one primary type of motion such as ascending or descending neighbor tones, while remaining close to the intoned or chosen interval. For instance, while the setting of “Se-” remains focused on the intoned perfect fifth, at the next syllable change to “-de” the repeated interval changes but is repeated no less frequently. The setting continues the same type of intervallic repetition and emphasis throughout the setting, with each section and syllable focusing on a specific interval.

Voice exchange can provide an additional type of sonic emphasis of a tone or interval through the exchange of range and the interweaving of the voice parts in the motion of one voice higher or lower than the other. This type of exchange is almost ubiquitous in Notre-Dame polyphony for many reasons. First, as all the polyphonic singers of the twelfth and early thirteenth century were male, the polyphonic singers of the twelfth century likely had very similar voice ranges, with several exceptions seen in the use of clef in the manuscripts. Considered in combination with the ambitus of the chant melodies, voice exchange is easily achieved in both composed or improvised polyphonic settings. This type of exchange adds an additional layer of aural complexity within polyphony, by creating obscurity between upper voices and tenor alike. Voice exchange between upper voices and tenor voices, is perhaps one of the only moments that the tenor voice, particularly a held tenor, can be obscured within the texture or rise to become part of the upper voice texture. This type of voice exchange can additionally serve to emphasize a particular pitch or interval through dramatic melodic motion, or through the unison singing of multiple voices on the same pitch. The examples below are but a few instances of voice exchange as sonic emphasis of a tone or interval.

The voice exchange in *Sederunt* provides some of the few moments the held tenor becomes part of the texture of the upper voices, rather than the constant aural background. The first such moment occurs following the syllable change of “de” in “Se-de-runt.” The tenor voice rises a third to sustain a new pitch at “de,” while first the duplum, then the triplum, descend a fifth to match the tenor pitch. Later in this same phrase the duplum voice descends from the pitch matching to tenor to drop below the tenor pitch, falling all the way to a fourth below (see figure 1.13). In the next phrase, following long 160, the triplum will also descend below the tenor.

Figure 1.14 Musical excerpt, perfections116-157, “De-” in *Sederunt*

For *Sederunt*, these moments of voice exchange are the only times in which the tenor becomes part of the upper voice texture. The held tenor tone is aurally distinctive from the moving notes, as the rhythmic measure ensures the sonic separation between tenor voice and upper voices. In these moments, the tenor is absorbed into the texture subsequently emphasizing the same tone as the duplum, providing what is notated as the fifth of the setting, and sustaining the repeated tone of the triplum line.

Terribilis features similar, rare moments of the tenor voice as part of the texture with the upper voices. These moments, it must be noted, can only be seen in the notation of F and not in Roesner’s edition. The edition transcribes the tenor voice into bass clef, which is not supported by the notation in the manuscript which notates all three voices of *Terribilis* in the c4 clef. Looking in F, the first moment of voice exchange happens just before the syllable change to “ri.” In this moment the duplum descends while the tenor ascends to facilitate the only moment of voice exchange with the tenor voice in this section of the setting. Voice exchange in “Cumque” occurs in the opening phrase. The second unit, which ends in a unison pitch in the duplum and triplum, is at a lower pitch than the tenor voice, following the tenor’s leap up a fifth. The most significant moment of unison in this setting is the ultimate note of both “Terribilis” and “Ait” which features a unison in all three voices. The terminal unison tone provides a strong aural conclusion to the setting, and places a great amount of sonic emphasis on both the end of the section and on the tone itself.

The melding of voice parts that occurs in voice exchange particularly in two-voice settings provide sonic emphasis with a textural shift from harmony to unison, from higher to lower, would be aurally significant and effective as sonic emphasis. In three and four-voice settings the use of voice exchange to double the tenor tone places sonic emphasis on that tone, particularly if a voice must descend beyond its established melodic range to reach the tenor tone. When the tenor is absorbed within the texture of the setting this enables the sustained emphasis of the lowest or middle voice of an interval. Voice exchange allows for an additional type of sonic emphasis through a vocal doubling between an upper and tenor voice.

Sonic emphasis serves not only to highlight a gesture, contour, or interval, but also to sustain the feature within the space, serving as both emphasis and sound production. Additionally, voice exchange can provide aural complexity, emphasizing inner voices or the tenor tone with melodic motion or repetition. Sonic emphasis would have been at the discretion and coordination of the polyphonic singers, as with great singing or improvisational accuracy these types of repeated and exchanged gestures discussed above could be successful. Conversely, errors in coordination could fail to resound the interval or gesture at the appropriate moment, either allowing the sound to fade or resulting in a more jarring emphasis of an incorrect interval. With great skill, polyphonic singers could have mixed techniques for sonic emphasis to repeat, resound, and sustain musical features within the cathedral space.

Conclusion

Analyzing the sonic implications of the repertoire considers the underlying inter-materiality between space, performers, and the repertoire. That is, my sound-based approach considers the new acoustic of a changing, evolving performance space and how rhythmic experimentation also functions as new techniques for sound production and sonic emphasis. By examining the sonic implications of rhythmic and textural features, we are able to ask new questions regarding rhythmic experimentation and performance practice, such as how the number of tenor singers correlates to the measure of the tenor voice or how long a tone must be sung to ring within the heights of the cathedral vaults. A sound-based analysis additionally engenders new directions of investigation within my own study, particularly relating to the challenges of sound production facing singers in two and three-voice settings. For instance, how much sound can be produced by a two or three-voice setting and to what extent does the shift in tenor measure alter sound production? Is mode five or double longs better for sound production? Quantifying some of the sonic implications identified within two and three-voice settings, which make up the overwhelming majority of settings recorded in Notre-Dame manuscript sources, will provide further insight into rhythmic and textural techniques of sound production and sonic emphasis. Thus, a sound-based analysis reveals the limitations of examining the music as separate from sound and separate from the space.

The sound-based, inter-material approach re-examines the “thingness” of the manuscript page, reconstituting the written page as a process rather than a product. As previous studies such as Butler, Dillion, and Eidsheim as well as my own illuminate, the sounds of Notre-Dame’s polyphonic practices can only be understood by considering the tensions and interplay between what is and is not on the page. The manuscripts preserve many indications of the thirteenth-century performance practice, however, the rhythmic experimentation also demonstrates the twelfth- and early thirteenth-century singers adjusting to a new acoustic space. The increasing use of discant rhythmic structures—creating evermore discant clausulae and copula settings such as those discussed above—could be one indication of the need for more sound within the space. Repetition and voice exchange serve as techniques to emphasize as well as resound within the reverberation of the cathedral to sustain a particular sound. The rhythmic experimentation that occurs in Notre-Dame polyphony indicates that the practices are adjusting and developing to address specific sonic concerns within the cathedral space. To further understand the necessary adjustments for polyphonic singers, it is to the cathedral space itself that we now turn.

The Structures for Sounding: The Physical Space and Performance Requirements

"As musicologists, we would love to pierce the veil of history and behold a first-hand the workings of liturgy, music, and ceremonial, especially during that half-century from about 1180 to 1230 when Notre-Dame polyphony enjoyed its greatest renown." -Rebecca Baltzer

When members of Notre-Dame's chapter entered their new choir in 1182, they must have been struck by the new heights of the vaults and the clamour of ongoing construction. After twenty or so years not worshipping in Notre-Dame, the choir would again be theirs for worship and performance for another forty years. However, the chapter would return to worship within a construction site as, over the next hundred years, their practices would be accompanied by on-going construction and renovations. The completion of the nave in 1220 more than doubled the size of the cathedral. In 1225, one hundred years of renovations began to alter and expand the cathedral, adding new windows and chapels in each bay. Musicologists including Edward Roesner and Craig Wright consider 1150-1250 to be Notre-Dame's most influential years on polyphony. Yet, the new cathedral was under construction for sixty of these hundred years and renovations in the choir and the addition of the lateral chapels took place through the thirteenth century continuing through the final forty years of Notre-Dame's influence. The practices of Notre-Dame's chapter were undoubtedly impacted by the lengthy construction as the chapter's worship continued through not only incomplete phases of construction, but also through the subsequent removal or walls, and alterations of size and materials. The extent to which singing and worship were affected through construction has yet to be fully explored.

This chapter explores sound making at Notre-Dame through the stages of its initial construction from the 1160s to 1320, investigating how sound making was impacted by the materials of and in the cathedral and the shifting acoustic space. It considers the way that construction altered the use of the space, noise levels, light, and how each phase of construction created a new performance environment for musical development and practices. Additionally this chapter details the timelines of musical and architectural development, considering the chronologies of both the musical repertoire and the cathedral to map their parallel developments. Comparing the timelines raises new inquiries into where the chapter worshipped during this period, and reveals just how much of the repertoire was created and performed in an absent or incomplete space. Finally, it examines the adjustments required of singers in response to their material surrounding and performance conditions and the rhythmic textures and performance practices at their disposal. Considering the singing body and the physicality of sound making through each stage of construction allows for the further examination of how the acoustic space, materials, and aural feedback affected music during a pivotal time of polyphonic development.

I begin by outlining the construction history to highlight the addition or modification of materials in, and that make up, the cathedral. Included in the construction history are the architectural features of the new cathedral as well as information about the donations and changes of personnel—architects, bishops, and king—each of whom yielded their own effects on the continued investment, quality, design, and results on the construction.

Accompanying the construction history are the known musical dates, concerning people, manuscripts, and polyphonic settings. These musical items and people serve as a guideline for considering the development and place of soundmaking during the late twelfth and early thirteenth centuries. For musicologists such as Wright and Roesner, the arrival of new musical figures such as Léonin and Pérotin have traditionally indicated, or been associated, with a new musical style within the cathedral. Here, however, Léonin and Pérotin serve as examples of what rhythmic techniques were available to singers at the time, but are otherwise confined to the timeline in favor of a broader discussion of the singers and their day-to-day practices.

Next, I explore where Notre-Dame's chapter might have worshipped throughout construction of the choir. Their need for an alternative worship space is a topic that has received little attention, but needs to be considered as yet another effect on the chapter's worship practices. Before the choir of the cathedral was completed, the chapter still needed to perform its daily services and worship duties. Conflicting information in the timeline of construction, when the chapter began services in the new choir, and location of the old church makes it difficult to determine precisely where, and for how long, the choir needed an alternative worship space. The chapter of Notre-Dame was located in close proximity to a large number of abbey churches, parish churches, and collegiate churches—some of which were under the purview of Notre-Dame. In this section, I explore the churches near Notre-Dame, their relation with

Notre-Dame chapters, and what is known about their ability to accomodate the Notre-Dame chapter to evaluate the most likely alternative worship space.

The final section of this chapter is devoted to a discussion of the singers and the adjustments necessary to adapt to the new performance space within the cathedral. The chapter's singers would have faced many challenges performing daily within the cathedral at each stage of construction—none of which have been considered in musicological literature. Not only the polyphonic soloist, but additionally the collective chanters, liturgy readers, and the soloists who intone the antiphons and responaries: all performed their daily services throughout construction. Though the polyphonic textures may have been in flux throughout this period, the traditions and practices of the chapter were well established providing some continuity and techniques and tools with which to adjust to the new cathedral. While the singers of polyphony are given the most consideration in this discussion, I do not disregard the presence and practices of the other solo and collective singers.

To discuss the singers' performance adjustments I draw from literature on contemporary and historical ensembles and their adjustments to performance spaces to examine how different materials and positions within the cathedral affect sound making. No surviving sources discuss how singing practices changed, or remained consistent during construction. However, modern acoustic experiments using singers including Deborah Howard and Laura Moretti's study of Renaissance Venice and Sharon Gerstel's study of Byzantine churches, reveal the ubiquity of singers needing to adapt to a new space and highlights a range of techniques which they could adjust their practices, including modifying the repertoire, changing the number of singers or vocal style, or changing the location of the singers.[177] Contemporary studies such as those by John Potter and Joseph Dyer additionally provide insight into how vocal ensembles respond to changes in performance conditions.[178] By engaging these contemporary sources, I can explore how the addition or subtraction of materials in the cathedral changed aural feedback and sound production.

A Note on the Construction Timeline

In what follows, the construction timeline of Notre-Dame has been divided into four stages of construction in concordance with those presented by Dany Sandron and Andrew Tallon:

Table 2.1 Construction stages and dating

Stage	Dating	Construction Completed
Planning	Pre 1163	Unknown
Consecration of the Altar	1163-1182	Completion of the choir
Completion of the Foundations	1182-1208	Completion of the transepts, and beginnings of nave walls and western facade
Nave Completion and Thirteenth-Century Renovations	1208-1320	Completion of Nave, western facade, new windows, and addition of

[177] Deborah Howard and Laura Moretti, *Sound and Space in Renaissance Venice: Architecture, Music, and Acoustics* (New Haven: Yale University Press, 2009). Spyridon Antonopoulous, Sharon E. J. Gerstel, Chris Kyriakakis, Konstantinos T. Raptis, and James Donahue, "Soundscapes of Byzantium" *Speculum* 92, no. 1 (October 2017): 321-335.

[178] John Potter, "Ensemble Singing" in *The Cambridge Companion to Singing,* ed. John Potter (Cambridge: Cambridge University Press, 2000), 158-164. John Potter, *Tenor: History of a Voice* (New Haven: Yale University Press, 2009). Joseph Dyer, "The Voice in the Middle Ages," in *The Cambridge Companion to Singing,* ed. John Potter (Cambridge: Cambridge University Press, 2000), 165-177.

		lateral chapels[179]

It should be noted that there is some crossover of construction within these phases—during each stage there is often work on more than one area of the cathedral. Additionally, the following timeline relies on the construction timelines and evidence presented by art historians Caroline Bruzelius, Andrew Tallon, and Dany Sandron, as their studies present evidence unavailable and unverifiable by me. It should be noted, however, that these studies are not definitive. First, in the Planning stage, I discuss what may have stood before the cathedral and the efforts of Bishop Maurice de Sully to make the cathedral construction possible, including activities such as land purchase. In the second stage, Consecration of the Altar, I outline the completion of the chevet of the cathedral, or the east end in which the choir and altars are located. This is the space in which the chapter sits to worship the hours. Third, in Completion of the Foundations, I outline the completion of the transept (the area of the cathedral that divides the choir and nave) and beginnings of the nave including the foundations and external walls. Finally, in fourth stage Nave Completion and Thirteenth-Century Renovations I discuss the completion of the nave walls and vaults, work on the western facade, and the renovations including new windows and addition of the lateral chapels. Each stage of construction has significant implications for the size of the cathedral, materials present, and the type of construction that will impact worship.

[179] Dany Sandron and Andrew Tallon, *Notre-Dame de Paris: Neuf Siècles de l'Histoire* (Paris: Parigramme, 2013).

Planning

There is conflicting information about whether there were one or two churches in place before the cathedral. Marcel Aubert, Andrew Tallon, and Dany Sandron hypothesize that St. Étienne and Notre-Dame were separate buildings while others such as Alain Erlande-Brandenburg argue that there was only one edifice dedicated to both Mary and Étienne.[180] Additionally, the location of these churches varies slightly in each study. Each study bases the placement of one edifice at the foundations of what is hypothesized to be St. Étienne, discovered by Archaeological excavation (seen below).[181] The placement of a second church, however, is unconfirmable without further study of the site below the current cathedral.[182] According to Erlande-Brandeburg, the church(es) received renovations during the twelfth century, including new windows, an elaborate portal door dedicated to the Virgin Mary, and possibly a new roof.[183] St.

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[180] Marcel Aubert, *La Cathédrale Notre-Dame de Paris: Notice Historique et Archéologique* (Paris: D. A. Longuet, 1909), 9-10, and "Les anciennes églises épiscopales de Paris, Saint-Étienne et Notre-Dame, au XIe siècle et au début du XIIe," *l'Académie des Inscriptions et Belles-Lettres* 83, no 3 (1939): 319-327. Alain Erlande-Brandenburg, *Notre-Dame de Paris*, trans. John Goodman (New York: Harry N. Abrams, 1998), 20 & 24.

[181] For instance, compare the location of the church in Tallon and Sandron's laser scan, with that of Aubert depicted in Fig. 1. In Tallon and Sandron's image, Saint-Étienne, the largest edifice, is surrounded by the baptistry, and smaller churches connected to the chapter including Saint-Christophe, Saint-Denis-du-Pas, and three unnamed churches in a parallel line. In Aubert's image, you can see the dashed outlines of an older version of Notre-Dame, and Saint-Étienne in relation to the outline of the cathedral as it stands today. The solid lines at left of the outline of Saint-Étienne are the foundations found in Archaeological excavation. The placement of Saint-Étienne in Tallon and Sandron's image also coincides with those foundations.

[182] A further study of the ground beneath the cathedral may occur in the years to come as scientists continue their study of the site in the wake of the roof fire. See: Christa Lesté-Lasserre, "Scientists are leading Notre Dame's restoration—and probing mysteries laid bare by its devastating fire" *Science,* March 12, 2020,
https://www.sciencemag.org/news/2020/03/scientists-are-leading-notre-dame-s-restoration-and-probing-mysteries-laid-bare-its

[183] Erlande-Brandenburg, *Notre-Dame de Paris*, 24 & 39. Aubert, "Les Anciennes Eglises," 324.

Étienne was large in stature—246 feet long by 115 feet wide or 74.6 meters by 35 meters wide at the facade—and likely in functional condition in 1160, with new decor.[184] St. Étienne was certainly large enough to accommodate the chapter and its practices and, post renovation, was believed to be "presentable" for the use of the chapter. But despite these renovations, the space was ultimately deemed inadequate for the choir's needs and the chapter's expanding prestige and personnel.

Figure 2.1 St. Étienne and the old Notre-Dame

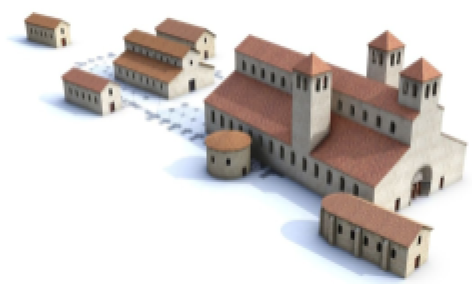

Image Tallon and Sandron's placement of the "la grande église," *Notre-Dame*, 12-13

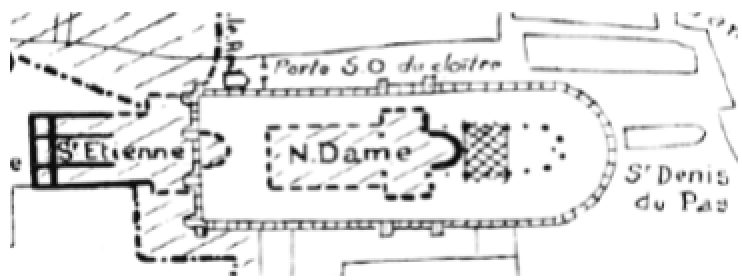

Image of Aubert's placement of St. Étienne and Notre-Dame, *Les anciennes églises,* 322.

Maurice de Sully ascended to the bishop's seat in 1160, and is thought to have immediately put in motion his plans to replace the church or churches with a new cathedral that would far surpass the size of the old.[185] The planned grandeur of the new cathedral would show the prestige of the bishopric of Paris in the newest architectural style.[186] Sully, with the support of the chapter, is thought to have commenced his plans to build the new expansive cathedral immediately by acquiring land and materials for the cathedral and new chapter house, as well as the square and street that would lead

[184] Erlande-Brandenburg, *Notre-Dame,* 39.

[185] Aubert, *Notre-Dame*, 26.

[186] Erlande-Brandenburg*, Notre-Dame*, 39-42.

to the cathedral.[187] The new edifice would dwarf those of the previous churches, requiring the demolition of both St. Étienne and Notre-Dame to make room for a space that was more than double the lengths and heights of both churches.[188] The intended size and grandeur required more stone, more glass, allowing a larger volume of space, and eventually the ability to fit more bodies within that space.

[187] Ibid., 45-47. Erlande-Brandenburg outlines what was a long and arduous purchase process, with several rounds of negotiation between the Bishop, chapter, and property owners in the area including individuals and the Abbey of St. Victor. Sully also had to deal with negotiations within the chapter on the size and allocations for new chapter houses and an expansion of the canons' complex.

[188] On cathedral planning see: Stefaan Van Liefferinge, "The Hemicycle of Notre-Dame of Paris: Gothic Design and Geometrical Knowledge in the Twelfth Century," *Journal of the Society of Architectural Historians* 69, no. 4 (December 2010): 490-507. Stefaan Van Liefferinge, *The Choir of Notre-Dame of Paris: An Inquiry into Twelfth-Century Mathematics and Early-Gothic Architecture*, PhD diss. (Columbia University, 2006). Michael T. Davis and Linda Elaine Neagley, "Mechanics and Meaning: Plan Design at Saint-Urban, Troyes and Saint-Ouen, Rouen," *Gesta* 39, no. 2 Robert Branner and the Gothic (2000): 161-182.

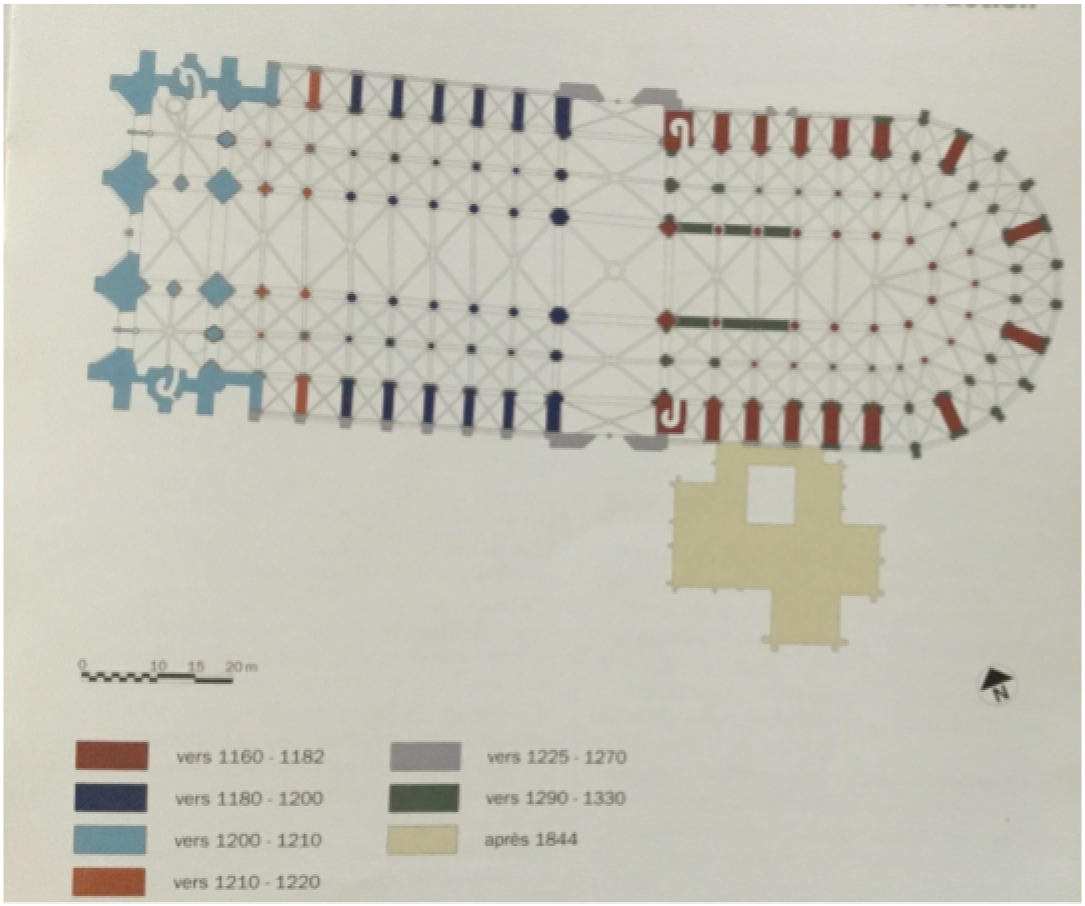

Figure 2.2 Notre-Dame floor plan with Tallon and Sandron construction dates. Image credit: Tallon and Sandron, *Notre-Dame*, 193.

Consecration of the Altar

In order to start construction, builders had to prepare the new foundations, erect large stone walls (initially supported by scaffolding), and build a roof and vaults as well as carve the capitals and install windows. The choir, at the edifice's east end, was the first portion of the cathedral completed. This work began no later than 1163 when Pope Alexander III (pope from 1159-1181) laid the first stone of the cathedral.[189] Donation

[189] *Gallica christiana* VII, vol. 71. Jean de Saint-Victor, *Memoriale historiarum*. Victor Mortet, *Étude historique et archéologique sur la cathédrale et la palais épiscopal de Paris* (Paris, 1888), 41-43. Clark argues that construction would have begun in 1150-55. Erlande-Brandenburg makes a case for construction beginning by 1160-1 when Maurice de Sully became Bishop who, as the main source of motivation for construction, wouldn't have wanted to wait to begin construction (39). For more on Pope

records further support the dating of the start of construction to the early 1160s are the records of donations. These records include Maurice de Sully's donation of 100 pounds, William of Barre's donation of 50 pounds and King Louis VII's donation of 200 pounds to the fabric of the church and land purchases, including the 1163 purchase of Henri Lionel's house to begin building the street in front of the future cathedral.[190] Art historian Marcel Aubert hypothesizes that around this time, St. Étienne and at least the choir of the previous Notre-Dame church was torn down to make way for construction.[191]

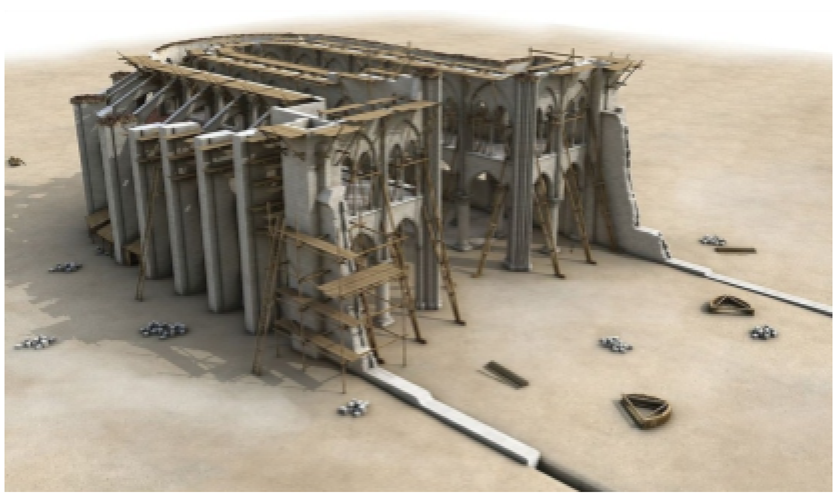

Figure 2.3 Construction progress on the chevet in 1170. Image credit: Tallon and Sandron, *Notre-Dame*, 24-25.

Construction began with the choir, pictured above, the space most needed for the practices and function of the chapter. Art historian Caroline Bruzelius, studying the plinth

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Alexander III see: Peter D. Clarke and Anne J. Duggan, eds., *Pope Alexander III (1159-81): The Art of Survival* (Farnham: Ashgate, 2012).

[190] AN L 892, no. 6. Tallon, Sandron, *Notre-Dame*, 22. Mortet, *Étude Historique*, 83. See also, Erlande-Brandenburg, *Notre-Dame*, 45.

[191] Aubert, "Les anciennes églises," 323-325.

designs in the cathedral hypothesizes that the chevet of the cathedral was built from the outer walls inward, and from the north side around the hemicycle to south.[192] The new exterior walls of the choir were three feet, or just under one meter thick, thinner than those of other cathedrals such as Lyon and Chartres, and made of limestone as were the columns and capitals.[193] Moving upward, construction on the tribunes, here referring to the gallery above the arcade and the second elevation level (seen the image above), began in the late 1160s or early 1170s; these were also built from the north to south, based on design elements in the bays connecting to the transept—particularly the change of respond design.[194] Based on the appearance of flyers, or flying buttresses, at Canterbury and Saint-Germain-des-Prés in 1176-7, Bruzelius also hypothesizes that double flyers were introduced around 1170.[195] These rough datings indicate that construction within this first phase moved quickly and efficiently, and with no delays in construction, enabling the space to be in use as soon as possible.

The amount of stone and the size of the transepts were altered during construction. In the 1170s, design changes were made including widening the transept

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[192] Caroline Bruzelius, "The Construction of Notre-Dame in Paris," in *The Art Bulletin* 69, no. 4 (December, 1987), 543.

[193] For the stone type see Erlande-Brandenberg, *Notre-Dame,* 54. For the wall thickness see Malcolm Hislop, *How to Build a Cathedral: constructing the story of a Medieval masterpiece* (New York: Bloomsbury, 2012), 43.

[194] Bruzelius, "The Construction of Notre-Dame in Paris," 549-550. On the south side, the responds change to a flat pilaster flanked by shafts instead of the engaged shafts seen on the north side.

[195] Ibid., 555. Debate remains ongoing on whether flying buttresses were part of the original design of Notre-Dame cathedral or a later addition. For information about flying buttresses see: William Clark and Robert Mark, "The First Flying Buttresses: A New Reconstruction of the Nave of Notre-Dame de Paris," *Art Bulletin* LXVI (1984), 47-65. Stephen Murray, "Notre-Dame of Paris and the Anticipation of Gothic," *The Art Bulletin* 80, no. 2 (June 1998): 228-253. E. Lefevre-Pontalis, "L'origine des arcs-boutants," *Congres archéologiques* Lxxxii (1919): 367-96. Eugène-Emmanuel Viollet-le-Duc, *Dictionnaire raisonné de l'architecture française du XIe au XVI siècle* I, 82 and II, 293. Louis Grodecki, "Les arcs-boutants de la cathédrale de Strasbourg et leur origine," *Gesta* 15, no 1/2 (1976): 1-2 & 43-51. Dieter Kimpel and Robert Suckale, *Die gotische Architektur in Frankreich, 1130-1270* (Munich: Hirmer, 1985), 150. Aubert, *Notre-Dame,* 44 & 88-106.

and using thinner pilaster in the transept and tribune were made, revising the design and perhaps suggesting a new, unknown second architect took over the project.[196] The use of thin pilasters in the tribune arcade, choir, and this new design continued into the first four bays of the Nave reducing the amount of stone and expanding floor space.[197] Despite the change in architect and the modifications to the design, the construction in this first phase is believed by art historians to have proceeded uninterrupted, and rather quickly, as the choir is reported to have been completed almost in its entirety in only fourteen years, by 1177.[198]

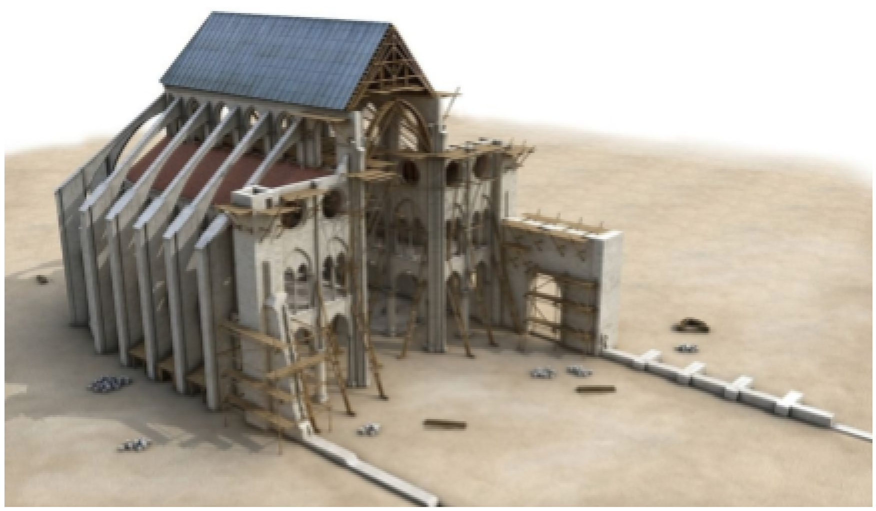

Figure 2.4 Construction progress in 1177. Image credit: Tallon and Sandron, *Notre-Dame*, 36-7.

Most consequential for dating the use of the choir is the completion of the choir's vaults. In the *Chronicles of the life of Robert de Torigni*, abbot of Mont-Saint-Michel, the

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[196] Erlande-Brandenburg, *Notre-Dame,* 86-89. Robert Branner, *Gothic Architecture* (New York: George Brazilier, 1967).

[197] Ibid., 89.

[198] Ibid., 62.

abbot documents his visit to the cathedral in 1177, reporting that the east end of the cathedral was "already finished, save for its vaults."[199] He states:

> "Mauricius, episcopus Parisiensis, jam diu est quod multum laborat et proficit in aedificatione ecclesiae praedictae civitatis, cujus caput jam perfectum est, excepto majori tectorio. Quod opus si perfectum fuerit..."
>
> "Maurice, Bishop of Paris, already for a long time has labored so much and progressed on the ecclesiastic edifice as [was] foretold to the citizens, of which the vital part has already been completed, except for the large/great covering. This work, supposing that it will be done…"[200]

Tectorio, the "great covering," is most often translated to mean vault, likely those of the main aisle, meaning that the roof of the building was in place before the vaults were constructed.[201] Supporting the absence of vaults at the time of Torigni's visit, a dendrochronological study conducted in 1997 dated the wood in the roof of the choir to a fell date just before 1177, which would indicate a quick turn-around time for completing either the roof or the framing of the vaults.[202] However, Erlande-Brandenburg contends that this fell date would provide enough time for the vaults to have been completed by 1182, in time for the consecration of the altar.[203] With the array of high status guests invited for the consecration, having the vaults in place for this occasion

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199 Burzelius, "The Construction of Notre-Dame in Paris," 555.

200 Leopold Delisle ed., *Chronique de Robert de Torigni, abbé du Mont-Saint-Michel, suivie de divers opuscules historiques de cet Auteur et du plusieurs Religieux de la même Abbaye*, (Rouen: A. Le Brument, 1873), 68. Translation mine.

201 See Bruzelius, "The Construction of Notre-Dame in Paris," 555. Erlande-Brandenburg, *Notre-Dame*, 55, and Andrew Tallon, "Rethinking Medieval Structure" in *New Approaches to Medieval Architecture,* eds. Robert Bork, William W. Clark, and Abby McGehee (Burlington: Ashgate, 2011), 209-217.

202 Virginie Chevrier, *La Charpente de la cathédrale Notre-Dame de Paris à travers la dendrochronologie: DEA sous la direction d'Anne Prache et GN. Lambert* (Paris: Université de Paris IV Sorbonne, 1995). Étude dendrochronologique de bois provenant de la charpente de la cathédrale Notre-Dame de Paris, Besançon, 1997. For more on vaulting practices see John Fitchen, *The Construction of Gothic Cathedrals: A Study of Medieval Vault Erection* (Chicago: The University of Chicago Press, 1961).

203 Erlande-Brandenburg, *Notre-Dame*, 55.

would be favorable, not to mention safer, for the chapter and Maurice de Sully to display their new cathedral. Before the consecration, the new choir was enclosed with a wooden wall at the west end to better facilitate the use of the space, separating and protecting the chapter's worship from construction, as can be seen Beauvais today.[204]

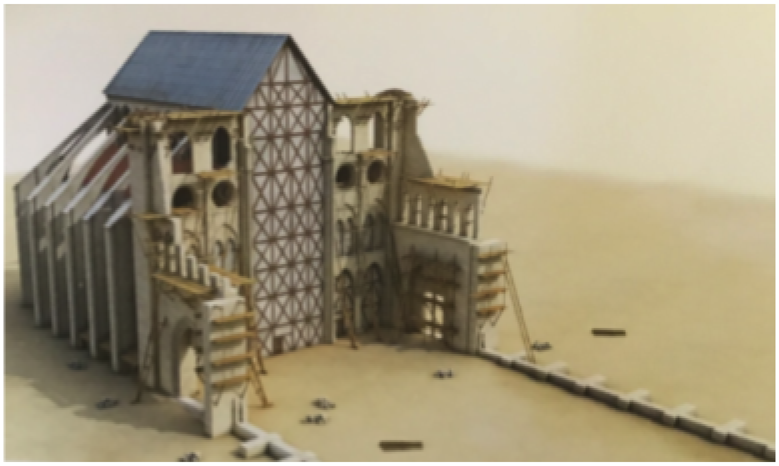

Figure 2.5 Construction progress in 1182. Image credit: Tallon and Sandron, *Notre-Dame*, 44-45.

The consecration of the altar on May 19th, 1182 likely indicates the use of the choir by the chapter.[205] The new choir and altar were decorated with a number of lavish donations made between 1175 and 1180. Donations include gold ornamented liturgical books donated by Dean Barbedor,[206] a gold chalice from Louis VII along with 2.5 marks of gold for the mass,[207] a pallium given by Ingeborg,[208] and possibly a retable from Philip

[204] Tallon and Sandron, *Notre-Dame,* 44-46.

[205] Ibid., 46; Bruzelius, "The Construction of Notre-Dame in Paris," 55. Aubert, *Notre-Dame*, 9.

[206] Tallon and Sandron, *Notre-Dame*, 53. Benjamin Guérard, ed., *Cartulaire de l'église Notre-Dame de Paris* IV (Paris, 1850), 153.

[207] Tallon and Sandron, *Notre-Dame,* 53. Guerard, *Cartulaire* 1, 270-271.

[208] Tallon and Sandron, *Notre-Dame,* 53.

Augustus.[209] Additionally, Alexander III gave 2 marcs for gold work,[210] and cantor Albert left twenty pounds to commission choir stalls at his death.[211] This space was used for over a decade before the next stage of construction would be completed.

Musical personnel and style are also changed through this first, transitory stage of construction. In 1177, magister Albertus Stampensis (Étampes), cantor from 1146 to 1177 died.[212] The Codex Calixtinus conserves a three-voice conductus attributed to Albertus sung at Notre-Dame.[213] Currently, there are no discussions of who succeeded Albertus, as cantor, but the musicological narrative places Léonin(us) as the next magister and composer for the chapter. Léonin, the lauded poet and oragnum composer, appears in documents from St. Benoit by 1179.[214] As discussed in the Introduction, Léonin is said to have created "a great many organa" settings, and to have compiled the first edition of the magnus liber—all of which must have occurred before 1201 when Léonin stopped appearing in archival documents.[215] With these dates placing him at Notre-Dame between 1179 and 1201, Léonin would have been present in time for the consecration of the new choir.

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209 Ibid., 53. For more donations see Appendix 1.

210 Guérard, *Cartulaire* IV, 170.

211 Tallon and Sandron, *Notre-Dame*, 53.

212 Craig Wright, *Music and Ceremony at Notre Dame of Paris* (Cambridge: Cambridge University Press,1989), 279. AN, LL 76, 642 & 661.

213 Wright, *Music and Ceremony,* 278. For other Notre-Dame sequences and conductus in the Codex Calixtinus see Margot Fassler, "Who was Adam of St. Victor? The Evidence of the Sequence Manuscripts" *Journal of the American Musicological Society* 37, no. 2 (Summer, 1984), 233-269.

214 Craig Wright, "Léoninus, Poet and Musician" *Journal of the American Musicological Society* 39, no. 1 (Spring 1986): 11. Musicological narratives including only Léonin and Pérotin include Wright, *Music and Ceremony.* Margot Fassler, *Music in the Medieval West* (New York: W. W. Norton and Company, 2014). Richard Taruskin, ed., *New Oxford History of Music* 2 (London: Oxford University Press 1957-1968).

215 Wright, "Léoninus," 11.

As indicated by the prevalence of two voice settings in manuscripts, two-voice organum was an increasingly prominent musical texture at least in the 1170s and 1180s: perhaps, the inclusion of this repertoire testifies to the presence of new personnel. Léonin's title of "master of organum" indicates that the genre existed before his arrival, but he created many more settings of this type. The manuscripts F, W1, and W2 all contain large sections of two-voice organa that seem to have continued to be sung even after the rise in popularity of discant.[216] As stated previously, Bloxam hypothesizes that the two-voice setting of *Terribilis v. Cumque Evigilaset Iacob* was created and sung for the consecration of the new choir in 1182, further highlighting the prestige of the organa texture.[217] However, one should note the possibility that few of the oragna settings were created within or for the choir, as will be discussed below. With the new organa additions to the repertoire, musical practices of this period included two and three-voice settings including organa, sequences, and conducti as well as chant and the solo intoning of antiphons and responsories. At the end of this stage of construction, the chapter was able to worship within their new choir, using their pre-existing musical repertoire and practices.

Completion of the Foundations

This second stage of construction saw vast progress as work commenced on the entire western end of the cathedral. By 1208 the transept and eastern bays of the nave

[216] Hans Tischler, "The Evolution of the 'Magnus Liber Organi'" *The Musical Quarterly* 70, no. 2 (Spring, 1984): 163-174. Janet Knapp, "Polyphony at Notre Dame of Paris" in *The Early Middle Ages to 1300, 2nd edition,* eds. Richard Crocker and David Hiley (Oxford: Oxford University Press, 1990): 557-635.

[217] Jennifer Bloxam "Preaching to the Choir?: Obrecht's Motet for the Dedication of a Church" in *Music and Culture in the Middle Ages and Beyond: Liturgy, Sources, Symbolism* eds. Benjamin Brand and David J Rothenberg (Cambridge: Cambridge University Press, 2016): 266.

were complete in their entirety and the other nave bays and facade were underway. The original dedication to the size and grandeur planned for the cathedral continued despite a change of bishop, architect, and even king as Philip Augustus ascended the throne in 1180.[218] Eudes (Odo) de Sully became bishop in 1196 (but would pass away at the end of this stage in 1208) and continued Maurice's initial plans, working to acquire yet more land to accommodate the size of the new edifice to the west. Archival evidence indicates that these negotiations delayed construction of the modified transept and nave bays, as will be discussed below. Construction was additionally slowed by the need to raze the newly purchased houses of Hôtel-Dieu to the west.[219] In spite of the delays and land disputes, in this stage builders put in place the foundations of the entire cathedral, producing the first physical, experienceable indication of the full size of the planned cathedral.

Having begun in the 1170s, construction of the transept, the section of the church that separates the choir from the nave, was perhaps completed early in this phase. That the second architect increased the width of the transept beyond the aisle width at this time is indicated by Archaeological research that revealed the use of different stones in the masonry stubs, as well as different course heights and base designs.[220] With the expansion, the transept became the same width as the side aisles in the nave and choir. Art historian Alain Erlande-Brandenburg hypothesizes that there may have been

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[218] Tallon and Sandron, *Notre-Dame*, 22-23. Philip Augustus made multiple donations to the church, including the one listed above, see Appendix 1.

[219] Mortet, *Étude historique*, 46. Aubert, *Notre-Dame*, 34. Bruzelius, "The Construction of Notre-Dame in Paris," 562.

[220] Erlande-Brandenburg, *Notre-Dame,* 65.

doors on both the north and south transept facades, and possibly rose windows.[221] The completion of the transept would have provided more protected worship space through which the chapter could process through while still remaining under a roof. A quick completion of the transept meant more workers were available at this stage to begin construction of the nave.[222]

Figure 2.6 Construction progress in 1208. Image credit: Tallon and Sandron, *Notre-Dame*, 56-57.

Work on the nave and the western façade was well underway by 1208, as it progressed concurrently with construction on the transept. The eastern bays of the nave are hypothesized to have been completed by the end of the twelfth century, including the roof and vaults. Bruzelius' analysis of the masonry work and the style of the elevation shafts indicates that the construction of the nave was begun sometime in the 1170s. Between 1180 and 1190, construction had already advanced to the upper stories of the east bays of the nave. Money for the roof was donated by Maurice de Sully at his

[221] Ibid., 87-89.

[222] Bruzelius, "The Construction of Notre-Dame in Paris," 563.

death in 1196, providing a possible date for the completion of these bays.[223] To the west, the foundations of the nave's west bays and western façade were under excavation by 1186.[224] The façade's ground level was constructed north to south with stylistic features matching those of the eastern bays, suggesting concurrent work.[225] The façade was additionally thickened between 1195-1200 in a revision to support the weight of the future towers and gallery. The decision to increase the size of the façade was possibly due to a change in architect, with the third master taking over the project in the 1190s, during work on the south side of the nave.[226] Changes in stylistic features between the north and south side of the facade may indicate a halt in work as use of the land was negotiated, perhaps for a number of years before the houses were able to be demolished.[227] By 1208 only the east bays of the nave were completed with vaults, affording even more protection for the chapter's to possibly use the transept. In place as well were at least the beginnings of all the walls that were to fully separate the cathedral from the outside world.

Development of the musical repertoire occurred simultaneously to construction, as indicated by the existence of our earliest record of the performance of four-voice polyphony. In 1198, Bishop Odo of Sully issued an ordinance concerning the behavior of

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[223] Aubert, *Notre-Dame*, 33. Guérard, *Cartulaire* IV, 145.

[224] Robert do Torigni mentions the discovery of relics forgotten beneath the city in Torigni, *Chronique* II, 136. Bruzelius, "The Construction in Notre-Dame of Paris," 561.

[225] Bruzelius, "The Construction in Notre-Dame of Paris," 561.

[226] Ibid., 561-562. See also W. Sauerlander, "Die Kunstgeschichtliche Stellung der Westportale von Notre-Dame in Paris," *Marburger Jahrbuch für Kunstwissenschaft* xvii (1959): 1-56. Jean Bony, *French Gothic Architecture of the12th and 13th Centuries* (Berkeley: University of California Press, 1983), 239 who date this alteration significantly later, in 1215.

[227] W. Sauerländer, *Gothic Sculpture in France, 1140-1270* (London: HN Abrams, 1972), 456-57. Bruzelius, "Construction of Notre-Dame in Paris," 562-564.

the clerics during the Feast of Fools, dictating the singing practices that should occur on the occasion: “the gradual [Viderunt Omnes] and Alleluia [Dies sanctificatus] will be sung in two-voice, three-voice, or four-voice organum in silk copes.”[228] This passage has been interpreted by scholars including Wright and Everist to indicate that Pérotin’s *quadrupla* settings were being performed at the time. In addition to Odo of Sully’s statement, and the resulting dating of *Viderunt* to 1198 and *Sederunt* to 1199, other mentions of the use of four-voice settings emerge during this stage. The obituaries of Odo of Sully in 1208 and Hugo of Clemens in 1217 also include mention of singing in three or four voices.[229] Considered together, these records suggest the increasing use of the previously unmentioned, and possibly rare, four-voice polyphony in practices at the turn into the thirteenth century.

The use of four-voice polyphony has also been interpreted to herald the presence and possible arrival of Pérotin, called the “master of discant” by Anonymous IV in his thirteenth-century treatise.[230] The dating of Pérotin’s arrival at the cathedral is uncertain, but it is likely he was present by the 1190s if not earlier. If Pérotin was indeed appointed succentor by the end of this third stage of construction, this would have placed him in charge of the music and worship within the incomplete cathedral space, and provided him the platform to create a large number of new polyphonic settings. Additionally, as discussed in the Introduction, his presence by the 1190s could also, as Sanders argues, indicate that the second edition of the *Magnus Liber* was underway at this time, which would have recorded the practices of a repertoire very much in flux. By

[228] Wright, *Music and Ceremony*, 240.

[229] Guérard, *Cartulaire* IV, 5 & 107-108.

[230] Anonymous IV, *The Music Treatise of Anonymous IV: a new translation*, trans. Jeremy Yudkin (Stuttgart: Hänssler-Verlag, 1985).

1208, according to the aforementioned archival documents, the singers repertoire included three and four-voice rhythmic discant and organa settings, added to their two-voice organa and three-voice conducti. The change in rhythm and texture is one indication of the singers adjusting to their new choir space through this twenty-six year stage of construction, as work progressed towards a complete cathedral.[231] Soon, the choir would have access to their full worship space upon completion of the nave vaults.

Nave completion and Thirteenth-Century Renovations

The final stage of the early construction history ends not with the completion of the nave, but with the addition of the chantry chapels around the cathedral. Following the completion of the nave, work began on the cathedral's interior once more to replace the windows and build thirty-seven new chapels to expand worship thanks to donations made to the cathedral. To facilitate the work, Bishop William of Auvergne (elected 1228) also had to handle yet more land acquisition, minor disaster, and monetary donations that enabled the construction of the lateral or lateral chapels. The renovation of new, larger windows in the choir and nave and the addition of the chancellor chapels continued the disruption of the chapter's worship to remove and replace stone and glass for an approximate additional hundred years.[232] This phase also significantly alters the reflective materials in the choir, as stone is systematically replaced with more glass.

Work remained on the vaults of the nave's western bays as did construction of the towers and façade sculpting. Around 1218, the final vaults were being put in place

[231] For more on the musical development during this period, see the Introduction.

[232] Erlande-Brandenburg in *Notre-Dame,* doesn't explicitly detail the need to renovate the windows also in the nave, but in the laser scan images produced by Tallon and Sandron the nave windows are depicted as the same size as those in the choir. See Tallon and Sandron, *Notre-Dame*, 68-69 & 82-83.

and completed by 1220. Louis VIII and Blanche of Castile gifted a chaplaincy for an altar in the outer aisle on the south side of the nave in 1218, indicating that the aisles were likely completed and accessible.[233] During the completion of the vaults, builders also had to contend with rebuilding the cathedral's roof after a fire in 1218.[234] Work on the west facade would continue with the gallery, hypothesized to have been constructed quickly, also being completed in the 1220s. Work on the towers would continue into the 1230s and as late as 1240s as sculpting continued as late as 1245.[235] If not for the renovations begun in the late 1220s, the cathedral would have been fully functional with the completion of the nave vaults. However, the chapter could have enjoyed the unrestricted use of the cathedral for five years before work on the choir began once more.

Figure 2.7 Construction progress in 1225. Image credit: Tallon and Sandron, *Notre-Dame,* 82-83.

[233] Aubert, *Notre-Dame*, 139. Henry Kraus, *Gold was the mortar: the economics of cathedral building* (Boston: Routledge & Kegan Paul, 1979), 215.

[234] Olivier de Chalus, "L'incendie de 1218 à Notre-Dame de Paris" *Scientifiques de Notre-Dame,* June 13, 2019, https://www.scientifiquesnotre-dame.org/incendies-dans-l-histoire

[235] Bruzelius, "The Construction in Notre-Dame of Paris," 566.

The windows in the choir prior to renovations emitted lower levels of light compared to contemporary cathedral windows, due to their small size. Before 1225 the windows created two separate elevations in the choir: smaller, round oculus windows below tall, possible narrow clerestory windows. A recreation of the two types of windows and elevations can be seen in Violet-le-Duc's restoration in the bays leading into the transept, as can be seen in the cathedral today and in the image below. However, cathedrals such as those at Chartres had eschewed the four-story elevation in favor of large clerestory windows that consumed the height of the cathedrals walls above the gallery.[236] Not to be outdone, the chapter at Notre-Dame decided to replace the windows in the choir and nave with new, large clerestory windows. The replacement of olders windows with new, larger ones required the removal of stone and, in the choir, could have required the alteration of the vaults.[237] The new windows dominated the wall space, replacing the stone and resulting in new reflective surfaces beneath the vaults.

[236] Bony, *French Gothic Architecture*, 357-464. See also Erlande-Brandenburg, *Notre-Dame*, 73-74.

[237] Bruzelius, "The Construction in Notre-Dame of Paris," 565. Aubert, *Notre-Dame*, 73-75.

Figure 2.8 Image of four-story elevation. Here, from top to bottom, you can see the clerestory windows, oculus windows, gallery, and arcade of the North Transept.
Image credit: Stephen Murray, *Mapping Gothic France, Media Center for Art History, Department of Art History and Archeology Columbia University*

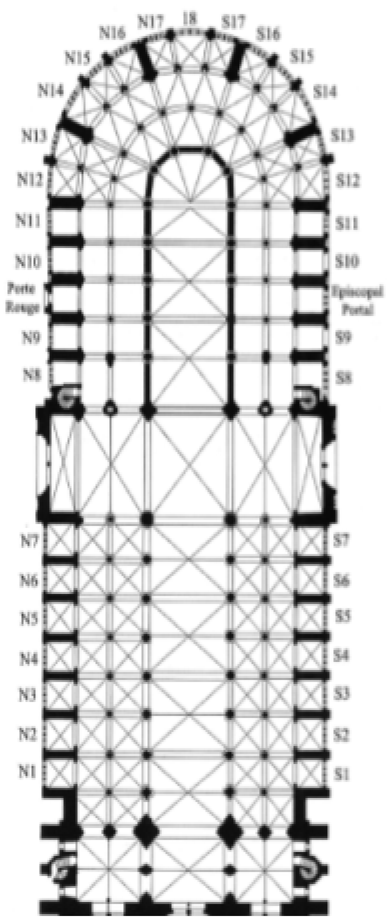
Construction of the chantry chapels added another nearly hundred years of work on the cathedral, with the nave chapels taking up most of that time.[238] To make room for the chapels, demolition of the outer Nave walls began no earlier than 1228, when William of Auvergne was appointed bishop of Notre-Dame cathedral.[239] Donations made for the chapels provide at least a rough dating as to their completion dates, including: a donation in 1236 for a purchase related to the chapel of St. James on the south side, the funding and establishment in 1241 of the chapel of St. Michael, Blanche of Castile gave money for the alta of Saints Bartholomew and Vincent on the south side in 1252,

[238] Mailan S. Doquang, “The Lateral Chapels of Notre-Dame in Context” in *Gesta* 50, no. 2 (2011): 137. The dating of this construction has also been discussed by: Aubert, *Notre-Dame* and Dieter Kimpel, *Die Querhausärme von Notre-Dame zu Paris und ihre Skulpturen* (PhD Diss, Rheinische-Friedrich-Wilhelms-Universität, Bonn, 1971), 31-43. Additionally, further sources were discovered by Henry Kraus, “New Documents for Notre-Dame’s Early Chapels,” *Gazette des beaux-arts* 74 (1969): 131-134.

[239] See Doquang’s discussion of Guillaume’s biography, and likely high involvement in the construction of the chapels due to his belief in purgatory, “Lateral Chapels,” 150-151.

and in 1285, Henri Tuebeuf, canon and subdeacon at the cathedral, provided funds for a chantry in the chapel of St. Leonard on the north side.[240] Though these donations do not date the chapels with absolute certainty, stylistic analysis of the differences between chapels such as window height, capitals, and niches within the walls of the chapels suggests that the chapels in the nave took approximately sixty years to remove walls, construct vaults, and rebuild the external walls for the chapels.[241] After completing the nave chapels, the chapter is thought to have had a ten year respite from construction before work on the choir's chapels began.

Figure 2.9 Lateral chapel dedications



Chapel Number & Dedication Name(s)

N1: St. Leonard Chapel
N2: SS George and Blaise
N3: St. Genevieve
N4: St. Lawrence
S4: SS. Michael and Antoine
S3: St. James and Philip
S2: SS. Bartholomew and Vincent
S1: St. Anne
N5: SS. Julian the Hospitaller and Mary of Egypt
N6: St. Catherine
N7: St. Nicholas
N8: SS. Jean and Agnes
N9: St. Eustache
N10: SS. Jean-Baptiste and Madeline
N11: SS. Ferréol and Ferjeux
N12: SS Anne and Michael
N13: St. Martin
N14: St. Faith
N15: St. Eutrope
N16: St. Jean-Baptiste
N17: St. Rigobert
18: St. Louis
S17: St. Nicaise
S16: St Stephen
S15: SS. Crispin and Crispinian
S14: St James
S13: St Stephen
S12: St Peter
S11: SS. Denis and George
S10: St. Gerald
S9: SS. Peter and Paul
S8: unknown
S7: St. Marie Madeleine
S6: St. Augustin
S5: St. Thomas of Canterbury

[240] Doquang, "The Lateral Chapels", 144. For a more complete listing of altar donations see Appendix 1.

[241] Ibid., 148-153. See also: Aubert, *Notre-Dame*,138-139.

The addition of the chantry chapels in the choir was the second round of major construction in the choir requiring the removal of stone walls. Work in the choir took less time, lasting from approximately 1296 to 1320, as the choir had fewer bays to complete.[242] But building the chapels in the hemicycle, which had fewer buttresses, meant the alteration of larger sections of walls at a time because the chapels in the hemicycle combined two or three chapels within one unified space.[243] The dating of these chapels correlates to figures buried in or responsible for the work. For instance, Aubert, Doquang, Sandron, and Tallon credit Bishop Simon de Buci as the initiator and overseer of this construction until his death in 1304 when he was buried in the axial chapel.[244] In 1316 Eudes de Sens was buried in the chapel of Saints Peter and Stephen, indicating that the chapel was complete.[245] The new chapels in the choir created not only more volume for the singers to contend with but also more reflective surfaces and more materials within the choir.

Finally, the transept was extended and remodeled to match the width of the chapels while the nave chapels were under construction. Architect Jean de Chelles was hired to complete the extension and his design for the transept included new, larger rose windows and a fully sculpted facade to match the new Rayonnant style emerging in Paris.[246] The extension of the transept was taken over by Pierre de Montrueil in 1257,

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[242] Doquang, "The Lateral Chapels," 150.

[243] Ibid., 150.

[244] Aubert, *Notre-Dame,* 13. Doquang, "The Lateral Chapels," 150. Tallon and Sandron, *Notre-Dame*, 127.

[245] Tallon and Sandron, *Notre-Dame*, 127.

[246] Ibid., 135.

following the tragic accident of Jean de Chelles that ended his career.[247] It was Pierre de Montrueil who supervised the completion of construction on the south transept. The construction on the transepts was likely completed before the beginnings of the hemicycle chapels.[248] These modifications to the transept created a consistent width through the cathedral and changed the reflective surfaces and materials through the removal of stone to make way for the larger windows.

Musical developments continued throughout renovations, including new settings and the compilation of the repertoire. Thomas Payne's dating of *Beata Viscera* dates Pérotin's joint composition with Phillip the Chancellor's text ca. 1218—only two years before the completion of the nave.[249] Records of the "master of discant" end well before the completion of renovations, as Pérotin's presence at the cathedral seems to have continued until the late 1230s or 1240s. What we know of Pérotin's career places him at the cathedral and possibly musically active in the incomplete choir, complete cathedral, and through the beginnings of the cathedral renovations in the choir that is, from the second stage of construction through the fourth.

By the end of the thirteenth century the musical practices of the cathedral were codified and disseminated with the copying of our only extant manuscript sources. As discussed in the introduction chapter, the polyphonic manuscripts W1, F, W2, Ma, and LoA are all dated between 1230 and 1320.[250] So too were the music treatises of

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[247] Ibid., 136. Erlande-Brandenburg, *Notre-Dame*, 159.

[248] Doquang, "The Lateral Chapels," 145-147.

[249] Thomas B. Payne, "Chancellor *versus* Bishop: The Conflict Between Philip the Chancellor and Guillaume d'Auvergne in Poetry and Music," in *Philippe le Chancelier: prédicateur, théologien, et poète parisien de début du XIIIe siècle*, eds. Gilbert Dahan and Anne-Zoe Rillon-Marne (Turnhout: Brepols, 2017), 265-306.

[250] See "Notre-Dame" in the Introduction.

Johannes de Garlandia, Lambertus, Franco de Cologne, Anonymous of St. Emmeram, and Anonymous IV, copied between 1240 and 1290.[251] The codification and dissemination of the repertoire begins even before renovations on the choir cease, calling into question which polyphonic practices the manuscripts contain.

Worship and sound-making at the cathedral were impacted by construction for over one hundred years with only brief periods of respite. The construction history above indicates that the size, amount, and types of materials, changed through each stage of construction. Between the 1160s and 1320s the development of the musical repertoire at Notre-Dame of Paris took place in a construction site. The chapter sang within the choir alone, in the cathedral with incomplete vaults, in a cathedral missing sections of the walls, and rarely within a space that wasn't competing with construction noises. And, for the first twenty years of construction, it is possible, if not likely, that neither the singers nor the chapter worshipped within Notre-Dame church or cathedral at all. The parallel development of the construction timeline and development of the repertoire suggests that the performance conditions and musical output were directly affected by the changes within the cathedral.

Worship during construction

Because of construction, worship had to occur within an alternative performance space for approximately twenty years. The altar's consecration in 1182 is an indication the vaults were completed and the choir was ready and safe for worship. Where the chapter worshipped during the construction of the choir is a matter of contention but rarely addressed. This discussion depends on many unknown variables and a large

[251] See "Notre-Dame" in the Introduction.

amount of speculation as no clear records exist about either when services began in the new choir, nor of when the nave of the previous church was torn down—the two most important variables in this discussion.[252] However, where services occurred during construction of the choir is a topic that affects sound making and the practices of the chapter during the first twenty or so years of construction.

Figure 2.10 Map of Medieval Paris. Image credit: Sandron, *Altas de Paris*, 129.

The chapter's options were numerous, as Notre-Dame was part of a thriving urban religious community. Directly connected to the chapter was Notre-Dame's "quatre-filles" St. Benoit (a collegiate church), St. Étienne-des-Grès (a parish church), St. Merry (a parish church), and St. Sepulchre (a chapel). Additionally, Notre-Dame was in close proximity to Saint-Germaine-l'Auxerrois (a parish church), Saint-Germain-des-Pres (an abbey church), Saint-Jacques-de-la-Boucherie (a parish church), St. Severin (a parish church), Saint Gervais (a parish church), and St. Victor (an Augustinian abbey) among others. However, Notre-Dame's chapter would have

[252] In future iterations of this project, I plan to extend the analysis of the earliest stages of construction and the spaces in place at the time to fully explore the possibilities and timing of demolition of the old church spaces.

considered the prestige and type of the institution, in addition to the size of space needed to accommodate their large numbers. To judge the size of each institution, which is one of the most important factors, I rely on the scaling of churches on historical maps of Paris such as Adolphe Berty's *Topographie historique de vieux Paris* and Philippe Lorentz and Dany Sandron's *Atlas de Paris au Moyen Age*.[253] I also weigh additional factors, such as prestige and the function of the spaces, as the chapter of Notre-Dame was invested in its image and connections. The chapter of Notre-Dame in the twelfth century held, and was concerned about, a high level of importance and prestige in Paris—they would have been unwilling to move to just any space, as will be discussed below. Directly impacting the perceived prestige of an institution from the eyes of Notre-Dame's chapter was the function of the institution: parish church as opposed to collegiate church or abbey. The type of institution would have implications for who was admitted into the space, its isolation from the public, its donors and patrons, and who was present within the institution. The chapter's alternative performance space not only needed to be able to fit the approximately one hundred-person chapter, it also likely needed to be an institution with an importance fitting of the chapter's stature.[254] Finally, the chapter having a connection to their host institution would also have made the transition and accomodation easier and more likely. In what follows, I discuss what is known about the churches in proximity to, and relationships with, Notre-Dame to explore possible alternative performance spaces during the construction of the Notre-Dame choir.

[253] Adolphe Berty, *Topographie historique de vieux Paris* vols 1-6 (Paris, 1866-1897). Philippe Lorentz and Dany Sandron, *Atlas de Paris au Moyen Âge* (Paris: Parigramme, 2006).

[254] Wright, *Music and Ceremony*, 19. Wright states that the chapter had 51 canons, who would have made up only a quarter of the clerical personnel. However, the archival documents cited that indicate 51 canons are dated from the thirteenth century or later.

The parish churches of Paris were the most numerous option for Notre-Dame chapter's alternative worship space. However, the majority of the parish churches are depicted as smaller church spaces too small to house the chapter. Indeed, St. Severin, Saint-Jolien-le-Pouvre, St-Jean-en-Greve, and Sainte-Opportune are indicated by Berty's *Topographie* and by Lorentz and Sandron to be too small to house the Notre-Dame chapter. Saint-Gervais and Saint-Jacques-de-la-Boucherie were larger parish churches, however neither of these spaces are likely to have hosted the chapter. Saint-Gervais is thought to have been under construction until 1177, limiting its potential use to the chapter.[255] Saint-Jacques-de-la-Boucherie is hypothesized to measure 31m by 15m—a similar size to the choir of Notre-Dame cathedral—and was completed in 1150 making it physically possible for the church space to fit the extra chapter, though the church was often under construction.[256] A popular parish church, Jacques-de-la-Boucherie was supported by wealthy merchants and nobility.[257] Because Notre-Dame's chapter was concerned with their prestige and image, the accessibility of parish churches to the general population of Paris may have been the most important factor to deter the Notre-Dame chapter from using any parish church as their alternative worship space. The chapter was construing a new, grand edifice to highlight the power and prestige of the bishop and the chapter as they carefully curated their image—the chapter hired a long lineage of musical figures and composers, had annual auditions for

[255] André Devèche, *L'Église Saint-Gervais et Saint-Protais de Paris* (Paris: Éditions de la Tourelle, 1974).

[256] Meredith Cohen, "Saint-Jacques de la Boucherie," *Paris, Past and Present,* University of California Los Angeles, 2017, http://paris.cdh.ucla.edu/saint-jacques-de-la-boucherie/

[257] Kraus, *Gold was the Mortar*, 33-38.

singers, and kept close ties with the University of Paris.[258] Further, records suggest that they may have resisted donations from merchants and tradesmen in the early stages of construction highlighting more separation between chapter and the laymen of Paris.[259] Notre-Dame's emphasis on prestige—of their institution and image—makes all Parish churches unlikely alternative locations, as the chapter would want to avoid mixing with the general public.

Notre-Dame had direct authority over its "quatre-fils" St. Sepulchre, St. Étienne-des-Grès, St. Merry, and St Benoit, however these spaces are unlikely to have hosted the chapter. Though the construction histories for the four spaces are unclear, the size and function of the quatre-fils are eliminating factors. St. Sepulchre was founded in 1000s, and reported to have been "seulemens...une chappel et une maison" or, only a chapel and house until the early fourteenth century making it entirely too small to host the chapter and suggesting that St. Sepulchre was under construction in the late thirteenth or early fourteenth century.[260] St. Étienne, a parish church given to Notre-Dame by King Henri I in 1038 (along with St Benoit), was located to the south but likely too small to accommodate the size of the chapter, as indicated by the size of the church in *Topographie*.[261] St. Merry, given to Notre-Dame in 1007, was larger than St. Étienne, however, both St. Merry and St. Étienne functioned as parish churches, and as

[258] Seen in the emphasis on hierarchy, singer auditions and positions (see below and Introduction chapter), not to mention their connection to the crown as described in the construction history. See also Wright, *Music and Ceremony*.

[259] Kraus, *Gold was the Mortar*, 29.

[260] AN L 586, no 3.

[261] AN LL 576, no 3.

such are also unlikely alternative spaces for the chapter of Notre-Dame.[262] Finally, St. Benoit was a collegiate church near St. Étienne on the south bank. Berty's *Topographie* indicates that St. Benoit was similar in size to St. Étienne, but, as a collegiate church, was the most likely space to host the chapter.[263] St. Benoit was occupied by six canons and twelve chaplains, making it a small institution.[264] The construction history of St. Benoit is unclear, however there is an indication that the church was under construction at some point between 1160 and 1183 meaning that it could not have hosted Notre-Dame's chapter.[265] With bigger and more prestigious institutions close by in Paris, the quatre-fils were unlikely candidates to host, which is further supported by the lack of archival records indicating that the chapter imposed themselves on one of these institutions.

St-Germain-des-Prés and St-Germain-l'Auxerrois would have been large enough to house the chapter of Notre-Dame as indicated by historical maps of Paris based on sources from the thirteenth century or later including *Topographie* and *Atlas Historique*. However, not only does the construction history of l'Auxerrois make it unclear if the church was an option, so too does the fact that Saint-Germain-l'Auxerrois was a parish church. Part of l'Auxerrois' foundations date back to the twelfth century, when it was hypothesized to have been begun.[266] As the church was under construction in the

[262] For dating, refer to AN L576, no 2. In regards to the size, see Lorentz and Sandron, *Atlas de Paris*, 139.

[263] Berty, *Topographie* 5, 222.

[264] M. Troche, "Notice Historique sur l'Ancienne Église Collégiale et Paroissiale de Saint-Benoît Quartier de la Sorbonne, A Paris," *Revue Archéologique* 4, no. 1 (1847): 224.

[265] Troche, "Notice Historique," 220.

[266] Berty, *Topographie I*, 135. See also: Lorentz and Sandron, *Atlas de Paris, 139.*

twelfth century, the timeline of which is unclear, Saint-Germain-l'Auxerrois is an unlikely candidate to host the chapter.[267] Saint-Germain-de-Prés was a large abbey church, also under construction in the twelfth century, but thought to have been consecrated by 1163—just in time for construction on Notre-Dame to begin.[268] Studies indicate that the cathedral was large enough to fit both the chapter of Saint-Germain and Notre-Dame. Additionally, Sandron describes Saint-Germain-des-Pres as an "opulent" establishment with large land holdings, and an institution capable of paying high taxes to the king.[269] Finally, Saint-Germain-de-Prés was under the purview of Maurice de Sully until 1163 when the chapter of Saint-Germain-de-Prés was granted the institution an exemption.[270] Saint-Germain-de-Prés had the size and prestige to be a candidate for an alternative worship space, however, with such a weak connection to Notre-Dame, it is not the most likely candidate. There was another institution with closer ties to Notre-Dame, more prestige, and the space not too far away.

St. Victor is the most likely alternative performance space due to its prestige and connection to the Notre-Dame chapter. By the end of the twelfth century, St. Victor was a renowned intellectual community, supported by the king, making it one of the most

[267] Joris-Karl Huysmans and Patricie Locmant, *Les églises de Paris: Saint-Julien-le-Pauvre, Saint-Séverin, Notre-Dame de Paris, Saint-Merry, Saint-Germain-l'Auxerrois* (Paris: Éditions de Paris, 2005). André Devèche, *L'Église Saint-Germain l'Auxerrois de Paris* (Paris: S.I.D.E.S & Éditions de la Tourelle, 1975).

[268] William W. Clark, "Spatial Innovations in the Chevet of Saint-Germain-des-Prés," *Journal of the Society of Architectural Historians* 38., no. 4 (December, 1979): 349. See also Adolphe Berty, *Topographie* 3 (Paris, 1866-1897), 103.

[269] Lorentz and Sandron, *Atlas de Paris*, 115.

[270] AN L 230, no. 21. Robert de Lasteyrie, *Cartulaire général de Paris, ou Recueil de documents relatifs à l'histoire et à la topographie de Paris, 528-1180* (Paris, 1887), 378.

prestigious institutions in Paris.[271] St. Victor was established in 1113 and is hypothesized to have been built rapidly, making it available to host in the late twelfth century.[272] There is little information about the size of the church, with the exception of some architectural features including the rose window, before the sixteenth century when records indicate a large church.[273] Both the *Topographie* and *Atlas de Paris au Moyen Age* indicate St. Victor was a well-sized space, only slightly smaller than that of Saint-Germain-des-Prés and comparable to Saint-Mery.[274] Additionally, there was a strong connection between St. Victor and the masters of Notre-Dame including Maurice de Sully, who is documented to have visited and interacted with the abbey quite often, and several of the musical figures including Adam of St. Victor, a cantor at Notre-Dame in the early twelfth century, Léonin, who was listed as a "frater" in a charter of St. Victor, and Pérotin, who, along with Léonin, was listed in St. Victor's obituaries.[275] The prestige and connections between Notre-Dame, Maurice de Sully, and St. Victor makes St. Victor the strongest candidate for the alternative performance space.

The old Notre-Dame church is the final option under consideration here. Complications in the timeline of construction and ambiguous information about the

[271] Paul Biver and Marie Louise Biver, "L'Abbaye Royale de Saint-Victor: Maison mère des chanoines réguliers de Saint-Victor dits victorins" in *Abbayes, monastères et couvents de Paris des origines à la fin du xVIIIe siècle,* eds. Paul Biver and Marie Louise Biver (Paris: Éditions d'histoire d'art, 1970), 149-162. See also Agnès Bos, "Saint-Victor" in *Les églises flamboyantes de Paris XV-XVI siècles* (Paris: Picard, 2003), 277-282 and Lorentz and Sandron*, Atlas de Paris*, 142-144. Meredith Cohen, "Paris, Past and Present," University of California, Los Angeles. http://paris.cdh.ucla.edu/

[272] Biver and Biver, "L'Abbaye Royale," 150; Bos, "Saint-Victor," 277.

[273] Bos, "Saint-Victor," 279-281. Biver, "L'Abbaye Royale de Saint-Victor," 152-153.

[274] Lorentz and Sandron, *Atlas de Paris*, 129.

[275] AN LL 1450, 2, fol. 147. BN, MS Latin 14673, fols. 161, 183, and 264. Wright, *Music and Ceremony*, 285. There are many other figures that connect the two institutions - the three cited examples are just the beginning of a long list.

location or locations of the previous church, however, casts doubts on the use of the previous church. As mentioned above, there is no consensus as to if there was one previous church or two separate spaces, nor can the exact location be confirmed. Further, the use of the previous church space depends on when the previous church was demolished, the exact location of the existing spaces when construction began, and when the chapter moved into the new cathedral.[276] Based on Bruzelius' construction timeline, it is unlikely that the chapter would have been able to use the previous Notre-Dame church (if there were two spaces) much past the 1160s, now would the Bishop's palace be completed until 1177.[277] Aubert, based on an archival document in which Maurice de Sully is asked to hold a treasure,[278] suggests that the previous church remained in use until 1177 when the chapter could have moved to the new choir. However, there are a number of complications with this timeline. First, is the issue of when the vaults were completed. As discussed above, it was most likely only the roof that was overhead in 1177. If the vaults were in place, why wouldn't the altar have been consecrated? But if the vaults were still under construction, it would have been unsafe for the choir to be underfoot while the vaults were being completed.

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[276] The dates of both the demolition of the old structure(s), the precise location of the old structures including the canon's houses, other churches such as the baptistry are also unknown, as is the exact date that the new choir started being used (though I support a reading of the choir being in use starting with the consecration). It wasn't unusual for the old structure to be in use for at least part of the construction of the new space. See: Liefferinge, "The Hemicycle of Notre-Dame of Paris," 496. Davis and Neagley, "Mechanics and Meaning,"165.

[277] Meredith Cohen, *The Sainte-Chapelle and the Construction of Sacral Monarchy: Royal Architecture in Thirteenth-Century Paris* (New York: Cambridge University Press, 2014), 16-17. Thierry Crépin-Leblond, *Recherches sur les palais épiscopaux en France au Moyen Âge (12e et 13e s.)*, PhD diss. (École nationale des chartes, 1987), 220.

[278] Lasteyrie, *Cartulaire général de Paris*, 425-426. In document 513, Sully is asked to hold some treasure, then housed at St. Victor, in "ecclesia majori" or the big church so it could be returned to the rightful owners. In document 514, Sully responds and asks abbot Guerin to come to St. Victor, implying that he didn't not move the treasor.

Second, if the transept and nave were already under construction in the 1170s, the old nave would have been in the way and was thus likely razed.[279] Finally, the size of the previous church or churches is unknown. If there was one large church, only half or less than half of it was available, meaning the chapter would have had to relocate the altars and worship in an incomplete space even before moving into the new cathedral.[280] With the timeline of construction, if the old choir remained standing, it would have been available temporarily and only through the first half of construction on the new choir, requiring the chapter to move to another location until the new choir could be used safely. The lack of information available about the previous church's location limits the consideration of the previous church space as the worship space during construction. But, because this church space would have been readily available and belonged to the chapter, it still remains a possible worship space during construction.

Before the new choir was completed, the singers sang beneath stone vaults no matter which alternative space they occupied. Of the most likely options—Saint-Germain-des-Prés, St. Victor, and the old Notre-Dame church—each had a type of stone vault, matching the construction trends of the time.[281] As such, the singers would have continued to experience the aural feedback of stones overhead and sound absorbing materials around them such as choir stalls, cloth, and bodies. The singers also would have interacted with the singers and personnel at the alternative location, exchanging ideas and perhaps new melodies over time. Though this exchange

[279] Though, Erlande-Brandenburg suggests that the old apse could have been the only thing necessary to raise during the completion of the transepts, *Notre-Dame*, 62.

[280] Tallon and Sandron, *Notre-Dame*, 15, states the church was 70 meters long. Erlande-Brandenburg, *Notre-Dame*, 39, states the church was possibly 246 feet long and 115 feet wide, or 75 meters long and 35 meters wide.

[281] Bony, *French Gothic Architecture*, 117-156.

cannot be qualified, it is hard to imagine that the singers of two institutions would not have had some influence on each other over ten or more years of sharing space. Additionally during this period new polyphonic settings were likely to have been created even before the completion of the new choir—making the alternative performance space part of the repertoire. However an alternative worship space shaped their performance and the repertoire, something that cannot be qualified here, beginning practices at the new Notre-Dame brought the singers its own challenges and adjustments.

Singing in Material Conditions

Placing the singers within the material conditions of the cathedral through each stage of its construction requires a consideration of what they sang, how many singers were singing at a time, where the singers were located, and what surrounded them—each element of which would have varied depending on the occasion. In what follows, I first outline what the singers were responsible for daily and throughout the liturgical calendar and how many sung at each hour and feast. Next, I discuss what is known of where singers and the rest of the chapter were placed within the choir for worship. Their location would have affected their experience of worship, particularly early in the construction, depending on whether they were standing closer to the altar or closer to the enclosing wooden wall to the west. Next, I discuss the performance conditions faced by the singers during each stage of construction, considering the materials of the cathedral as well as those other materials within their immediate surroundings such as fabrics, human bodies, and furniture. Here I also discuss techniques available that singers could have used to adjust their performances to each stage of construction, including different rhythmic textures, changing their physical locations, and double parts, as well as intentionally limiting their singing volume. Finally, as part of the material considerations I also examine the issue of noise, which services would have been affected, and how the proximity of noise could have affected singing and listening. This chapter offers the first discussion of the performance and material conditions through construction, opening new modes of inquiry into the relationship between sound, music, and space.

My examination of singing within Notre-Dame is informed by previous analyses of how materials, acoustics, and space affect performance conditions from both an acoustic and singer's perspective.[282] The acoustics tests of Howard and Moretti, and Gerstel and Kyriakakis both consider historical evidence, on-site acoustic testing, and performance to examine acoustic features including reverberation, clarity, and listener envelopment.[283] Particularly central to Gerstel and Kyriakakis' study are the sonic effects of the dome, which contains and reflects sound back to the singers below. While vaults are shaped and reflect sound differently, the importance of over-head reverberation and its effects on sound production and sound making are comparable. In Howard and Moretti's study, St. John's College Choir provided specific insight into the importance of materials surrounding the singers—how proximity to wood, stone, and other singers affect aural feedback and sound making. Both studies additionally emphasize the effect of a listener's position within the space of their listening

[282] This section is also informed by the church singing experiences of Gillian Gower, Jordan Hugh Sam, and Elizabeth Upton.

[283] Howard and Moretti, *Sound and Space.* Gerstel, Kyriakakis et al., "Soundscapes of Byzantium."

experience: that each church has optimal positions for listening that are in the best location under the vaults or domes, and within a certain proximity to the singers. Potter and Dyer further shed light on techniques of singing to adapt to the performance space, such as blend, tone quality, and listening.[284] Dyer, in his study of medieval singing, indicates that singers were likely concerned with their tone quality and practiced different falsetto and modal voicings to achieve the desired tone, suggesting that the concerns of the modern ensemble are perhaps not too different from those of the medieval ensemble. Potter, as a former member of early music ensembles including The Hilliard Ensemble and Red Byrd, has extensive experience with polyphonic repertoires and performing within medieval cathedrals. In his chapter “Ensembles Singing,” he provides techniques to practice and improve ensemble blend, coordination, and sound production within such spaces. Taken together, we can imagine how the singers at Notre-Dame adapted to their own performance space by considering the acoustic properties of materials and performance response to the materials present.

Before beginning an examination of the singers, it should be noted that much of this discussion is hypothetical and its historical accuracy is difficult to gauge for numerous reasons. Not only is the exact progression of construction unknown, but so too is much of the information about early singing practices, the number of chapter members, and any records of how the chapter functioned through construction are unavailable or undocumented. Further complicating an examination of singing conditions are the lack of equivalents of many situations in which the medieval singers would have found themselves in, such as performing in a choir stalls while various walls of the space were removed several meters behind or above them. As such, in what

[284] Dyer, “The Voice in the Middle Ages.” Potter, “Ensemble Singing.”

follows my exploration is based on a foundational assumption that the chapter would strive to disrupt their worship as little as possible, and that once in the cathedral, they would continue holding services within the cathedral no matter what construction work was underway. In doing so, they may have made decisions and alterations to their day-to-day practices that defy or resist ascribed worship practices such as doubling parts on a non-feast day.

Additionally embedded in this discussion is a further assumption that the singers and authorities in the chapter did, in fact, care about what singing and services sounded like, even if only that they needed to be able to hear the soloist intoning the chant, and they cared about ending chants together as a chapter. Evidence of the chapter caring about singing can be found in records from the fourteenth and fifteenth centuries that indicate the dean and cantor or succentor, depending on the importance of the feast, would have had a missal or notated breviary in front of them "so they might survey the progress of the service and assure that it conformed to the musical and textual traditions of the cathedral."[285] The flow and pacing of services would be greatly altered and slowed if one half of the chapter had to wait for the other half to catch up with their chanting. Preventing the rupture of unified group chanting amongst other types of singing, then, would have required some kind of change in practice, as will be discussed below. Though we will likely never find records from this period, as I outline below, singers must have made some adjustments to overcome the difficulties of worshipping during construction. With all this in mind, let us now turn to the singers.

The singers at Notre-Dame were responsible for a large amount of daily singing. The chapter worshipped the Benedictine hours, requiring the worship and performance

[285] Wright, *Music and Ceremony,* 100.

of nine services each day including Matins and Lauds (the night hours, sung at midnight except for the summer hours when they were sung at about 6pm), Prime, Terce, Mass, and Sext (the morning hours between 8:00am and noon) and Nones, Vespers, and Compline (the evening hours, between 3:30pm and 6:00pm).[286] Each hour required a different amount of singing. Matins required the most singing, likely why this service had its own clerks, and the service included: six pairs of psalms and antiphon and three lessons and responsories on non-feast days; 9 responsories and eighteen psalms on Sundays; and was quite a large service on feast days including nine psalms, nine antiphons, nine lessons, and nine responds divided into groups of three.[287] Lauds immediately followed Matins and on feast days consisted of five antiphons, four psalms, a canticle, a chapter, hymn, versicle, and concluding canticle and antiphons.[288] The lesser hours of Prime, Terce, Mass, and Sext consisted of psalms, antiphons, responsories, the six ordinary and five proper chants of Mass on feast days, readings, the Eucharist, and tropes for feast days.[289] At Vespers singers performed five psalms, responsories, the doxology (the Gloria), and antiphons plus additional repertoire on high ranking feast days. Finally, for Compline there was only a small amount of singing consisting of four psalms, a canticle, and hymns for feast days.[290] How much was sung

[286] Ibid., 103.

[287] Ibid., 102 & 109-110.

[288] Ibid., 115.

[289] Ibid., 116-117. The five proper chants include the introit, gradual, alleluia, offertory, and communion. The six ordinary chants are the kyrie, gloria, credo, sanctus, agnus dei, and ite missa est.

[290] Ibid., 108. The worship of Compline would continue to develop through the sixteen century to become more elaborate.

at each hour and the addition of polyphony also depended on the rank of that day in the liturgical calendar and the feast occasion.

The amount of polyphony that was sung and the number of singers was determined by the ranking of the feast. Only feast days had chants or polyphonic settings created for that specific occasion, and only feast occasions of a high ranking received polyphonic settings. Feasts were organized by a hierarchy of importance; from least to greatest importance they were: memorial, three lessons, nine lessons, semiduplex, duplex, and annual. Feasts of nine lessons and above received polyphony, but on feasts of three lessons singers still performed an increased amount of antiphons, responsories, and chants.[291] The importance of the feast also dictated the amount of polyphony used at the feast, and how many people sang. Annual feasts received the most polyphony, with settings created for the gradual and Alleluia for the feast day and the days of the octave, with as many as six polyphonic singers performing each setting.[292] For Duplex feasts, the gradual and Alleluia of only the feast day was performed by as many as four signers, while semi-duplex feasts received polyphony only for alleluia and was sung by as few as just two singers.[293] Vespers received the most polyphony on the feast day and throughout the octave, that is, the seven days after the feast day. During construction, the number of people present to hear the services and for feast masses would have varied depending on the space available for those outside of the chapter.

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[291] Ibid., 104.

[292] Ibid., 266.

[293] Ibid., 339. See also Chapter One.

The position of each chapter member within the choir and number of chapter members present varied with each feast, and would have affected the experience of singing and listening in the new choir. Each member had a position within the choir, organized by rank among the chapter.[294] Present most often were the low ranking and unbeneficed members, including the choir boys, matins singers, and canons without holy orders who occupied the north and south sides of the choir and who were responsible for most of the singing. The choir boys and canons without holy orders sat beneath the vaults in the most interior position, on benches in front of the choir stalls. In the wooden stalls, those commissioned by Cantor Albert, in two rows on either side of the choir sat the vicars, minor canons matins clerks, canons, subdeacons, priests, and deacons. The matins clerks sat in the middle of the benches on each side, behind the choir boys, putting them directly under the vaults, and also allowing them to easily move into the center of the space to sing. Amongst the subdeacons, priests, and deacons those with more superiority sat to the outside, with those who had been there less time closer to the middle, and all were divided equally between the north and south sides. Those individuals of greatest importance either sat nearest to, or facing the altar on the opposite end of the choir. Closest to the altar sat the bishop, chancellor, and penitentiary, when present. On the opposite end of the choir, the cantor, succentor, dean, and archdeacons sat facing the altar. Archival documents suggest that the higher ranking members of the chapter might only be present on the most important of occasions, leaving many seats either empty, or filled by someone they paid to be there in their stead.[295] Seated in these locations, the sonic experience would have varied for

[294] Ibid., 98-101.

[295] Ibid., 19-21.

individuals depending on their proximity to the altar, and centrality under the vaults as will be discussed below.

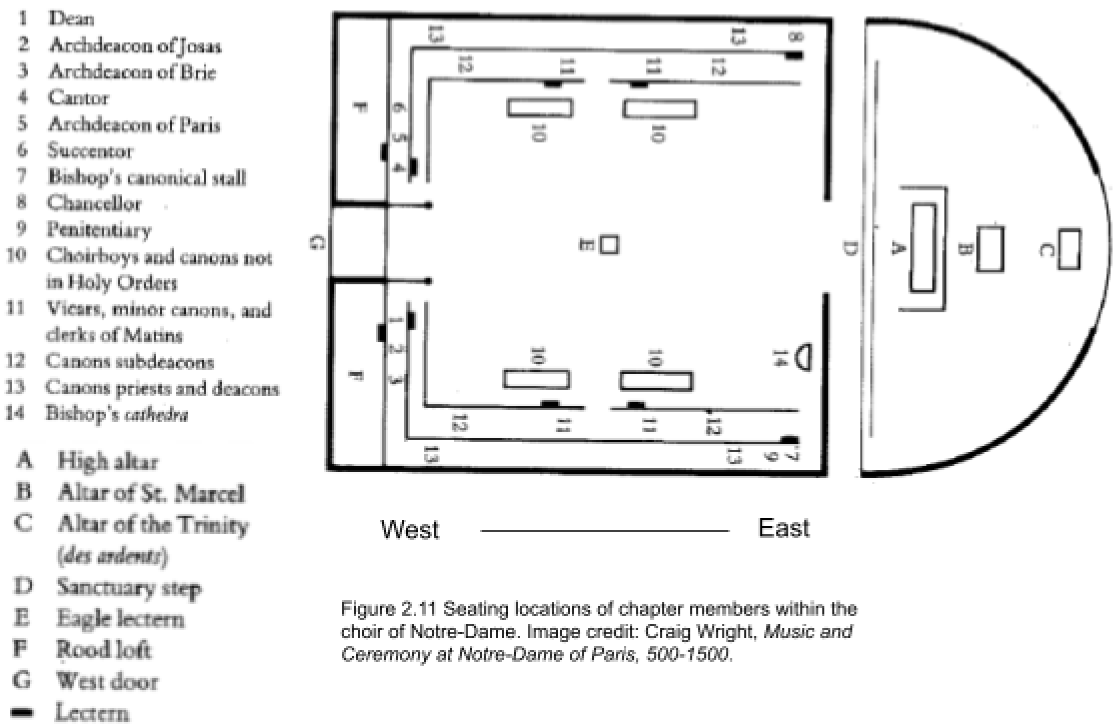

Figure 2.11 Seating locations of chapter members within the choir of Notre-Dame. Image credit: Craig Wright, *Music and Ceremony at Notre-Dame of Paris, 500-1500.*

The position of the singers within the choir depended on the type of singing and the ranking of the feast. No matter the occasion, the hymns, psalms, and antiphons were chanted from the choir stalls as each were already memorized by the chapter.[296] Soloists intoning the antiphons and responsories also performed from their place in the stalls, or from the steps leading into the stalls, as did the principal readers at the hours.[297] For most feast days, polyphonic singers descended from the choir stalls to sing beneath the vaults. The number of singers also depended on the rank of the feast. On feasts of lower ranking, such as three lessons, fewer singers performed and they

[296] Ibid., 101.

[297] Ibid., 101.

stood at the steps leading to the altar. Higher ranking feasts, such as those of semiduplex, duplex, or annual, involved more singers, as many as six for annual feasts, and were performed from the center of the choir.[298] Soloists would have faced the altar, singing into the resonance of the vaulted area in the choir.[299] The changing locations, then, also play a role in performance conditions and the singers' adjustments through construction.

Before moving into a discussion of the materials and singing, it is worth a brief reminder of the tenure, or lack thereof, of the polyphonic singers. Singer turnover occurred at the cathedral before and during each stage of construction. As mentioned in the Introduction, the matins singers were unbeneficed and had to audition annually.[300] Additionally, aging would have changed the suitability and presence of individual choir boys and older members of the chapter. As such, some of these transitions and adjustments would be made by a combination of new and experienced singers—some who had experience with the liturgical repertoire and some who had to learn both the space and the repertoire. For those singers present before and during significant changes in the cathedral, their adjustments to the new choir would be based on the materials that altered the performance conditions. In what follows, I hypothesize how the materials during each phase of construction could have affected performance, the ways the materials affected sound, and which techniques the performers could have utilized to make the necessary adjustments.

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[298] Ibid., 101.

[299] Anne Walters Robertson, *The Service-Books of the Royal Abbey of Saint-Denis: Images of Ritual and Music in the Middle Ages* (Oxford: Clarendon Press, 1991), 236.

[300] See "Notre-Dame: Source Materials" in the Introduction.

1182, Completion of the choir

The singers' new choir was a vast space in itself, with vaults at heights they'd never seen, as stone and glass ascended far beyond their heads. Their newly consecrated sanctuary was housed by large amounts of sound reflective stone and marble floors, the atmosphere created primarily by the natural lighting emitted through the windows that depended on the season. The new chevet had a large central aisle that housed the altar and in which the chapter stood and sat during the hours, framed by stone columns that lead out into the two side aisles with a second-story gallery above. At the far end of the choir from the altars, close to where the choir would sit to hear the mass, was the enclosing wooden wall—one of the many reminders of the space still to be added. Practices such as processions, and the placement of minor altars would have needed to be adjusted to the new spatial limitations. Additionally, the number of bodies and amount of materials surrounding the singers changed the amount of absorbing materials in their immediate surroundings while defining the signers' audience. The singing had to reach the ears of their fellow chapter members in order for worship to function efficiently despite any adverse performance conditions. The singers needed to adjust to the new height, light levels, and the contrast of sound absorbing and reflective materials.

Light levels in the cathedral would have been the easiest element for the singers in the new choir to overcome. Even during the day, the four-story elevation of the choir is thought to have been dimmer than newer and contemporary cathedrals due to its smaller windows.[301] The light that did enter the space was filtered through the colors of

[301] Erlande-Brandenburg, *Notre-Dame*, 67. Doquang also discusses the lower light level in Notre-Dame, particularly in the aisles: "Not only did the original, small windows limit the amount of light coming into the

the stained-glass, affecting light emission further. Additionally, the time of year and weather would impact the amount of sunlight and length of daylight hours. Darkness and shadow could, of course, be mitigated by adding candles and torches as was common practice, however these items would be too expensive to support daily practices.[302] But for the singers, improvisation and memorization, established practices even before this period, provided the techniques they needed to work within any lighting.[303] The low light levels might have even been a benefit for adapting to the new space, as the lack of sight could emphasize singers' and other celebrants' focus on the sound. Potter, in his discussion of ensemble singing, indicates that to focus on the ensemble's sound, singers can either shut their eyes or face away from one another to become hyper-aware of the sound, for both the collective ensemble and the individual parts.[304] Singing in low light, then, could have allowed singers to focus more intensely on the sound and aural feedback within the choir.

The biggest challenge to the singers' aural feedback was the contrast of singing under stone walls and vaults to the east opposed to in front of the wooden wall to the west. The stone vaults, with the keystone 32.7 meters above their head, created not only a large volume to fill with sound, but also a longer reverberation time.[305] As stone is

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aisles, but the projecting buttress piers likely created deep, persistent shadows that would have kept the aisles in almost perpetual darkness." Doquang, *Lateral Chapels,* 140.

[302] For more information about the use of torches and candles see Eamon Duffy, *The Stripping of the Altars: Traditional Religion in England 1400-1580* (New Haven: Yale University Press, 1992).

[303] See the discussion of oral and written practices in Chapter One and the discussion of the polyphonic singers and their training in the Introduction chapter. See also Wright, *Music and Ceremony*, 325-356.

[304] Potter, "Ensemble Singing," 163-164.

[305]Bruzelius, "The Construction of Notre-Dame in Paris," 555. See also: Stephen Murray, Andrew Tallon, and Rory O'Neill, *Mapping Gothic France*, Media Center for Art History, Columbia University and the Art Department, Vassar College, http://mappingGothic.org/building/1164#/

a highly reflective material for sound, sounds within stone cathedrals have long reverberation times that depend also on the length and width of the particular space.[306] The vaults of the choir would likely reflect the singers voice back down to the chapter while the sound continued to reverberate within the heights of the vaults. However, the wooden wall to the west of the space would absorb sound and deaden the sound reflections from the west. This would also affect the resonance overhead, as sound in the rounded vault of the hemicycle above the altar could sustain for a longer time than from the vaults above any singers standing to the far west of the space. As such, within the new choir each singer and listener had a different listening experience.

For the polyphonic singers, group chanters, and soloists the new choir presented different sonic challenges. The listening experience for those beneath reverberation created within the stone walls and vaults above the altar was a sharp contrast to that of those chapter members in close proximity of the wooden wall. Only the polyphonic singers had the advantage of being able to move within the choir to sing. For polyphonic singers, the uneven aural feedback could have been mitigated by moving farther east within the choir, closer to the hemicycle vaults in order to receive more aural feedback from the vaults above.[307] Being farther from the wooden wall would have allowed polyphonic singers to use the sound under the vaults more to their advantage, or at least would have allowed them to better hear the reflections from above. However, the

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306 Howard and Moretti, *Sound and Space*. See also: B. N. Postma and B. F. G. Katz, "Acoustics of Notre-Dame Cathedral de Paris," paper presented at *The 22nd International Congress on Acoustics*, *Buenos Aires*, *September, 2016. http://www.ica2016.org.ar/ica2016proceedings/ica2016/ICA2016-0269.pdf*. John Anderson and Torben Jacobsen, *RASTI Measurements in St. Pauls' Cathedral, London* (London: Bruel & Kjaer, 1985). Anne Schnoebelen, "Performance Practices at San Petronio in the Baroque," *Acta Musicologica* 41, no. 1/2 (January-June, 1969): 37-55.

307 Potter, "Ensemble Singing," 163. Howard and Moretti, *Sound and Space*, 30 & 42.

chanters remained stationary within the choir stalls, resulting in those closest to the wall receiving different aural feedback than those near the altar. While group chanting had the strength of numbers capable of filling their new vaults with sound, those in proximity to the wooden wall experienced a far deader sound due to the sound absorption of the wood directly to their right or left.[308] The contrast of aural feedback between the east end, those who benefitted from the hemicycle vaults, and west end of the choir may well have produced discrepancies in the volume or timing of chanters as those near the wooden wall received less reverberance from the space. In amongst the chanters, the soloists intoning the antiphons were at the greatest disadvantage. While the sounds of the previous chant still resonated within the vaults, soloists had to begin the next chant having to simultaneously overcome or blend with the sound still ringing, while projecting to be heard by those on the periphery of the seating arrangement. The deadening effect of the wooden wall may have served as an advantage to soloists, as it helped reduce the amount of sound necessary to project underneath the vast stone vaults, limiting the vocal strain on the soloists. Within the new choir, singers had to adapt to the aural feedback occuring vertically, with the new vaults overhead, and that of their surroundings.

Surrounding the singers were the bodies of their fellow chapter members, the choir stalls they sat within, and the fabrics that decorated the choir—all of which affected their sound. As discussed above, the number of bodies within the choir varied depending on the hour and day. Tallon and Sandron estimate that the choir was capable of holding a hundred people. A large number such as this would have been more common on major feast days, but, following the consecration of the altar, could also

308 Howard and Moretti, *Sound and Space,* 30.

have been present to celebrate their new choir.[309] Each body would be dressed in robes, and for feasts, copes were donned by polyphonic singers over their robes.[310] The choir stalls, made of wood, dominated the north and south sides of the choir, likely running the length of both bays of the apse with a high backing that extended up to the base of the capitals some six meters high. On important feast days, including the consecration of the altar, the choir would have been decorated with draperies, tapestries, carpets, and silks throughout the space, especially surrounding the altar.[311] The fabric, bodies, and wood each absorbed even more sound than had they not been present, but also defined the listening audience, and the areas sound needed to reach.

Figure 2.12 Image of cope, dated to the fourteenth century.
Image credit to: Victoria and Albert Museum

[309] This is suggested by the following quote, written by chronicler of Anchin: "For I saw him on a certain non-festal day, when the evening service was sung, not in his episcopal *cathedra* as was the custom, but with the others sitting and singing the psalms in the choir, surrounded by more than a hundred clerics." "Chronicle of Anchinc" VI, 421. Wright uses this quote as a testimony that services had already begun within the choir by 1182 and that the chronicler suggests that worshipping mass within the space "was in no way new." However, the bishop and the entire chapter (in addition to guests if the chronicler is there) being present on a non-festal day suggests the opposite, and that the chapter is still marveling at its new space. Wright, *Music and Ceremony*, 7.

[310] Wright, *Music and Ceremony*, 100.

[311] Ibid., 13-15. Duffy, *Striping of the Altars*, 22-36.

Feast occasions meant additional fabric hangings to elevate the festivities within the choir. The fabrics covered the stone and reduced reverberation, impacting the aural feedback of singers. With no specific information as to how many draperies, carpets, and other fabrics were put into place at the time, it is difficult to judge the precise effect of such materials on singing. However, the textiles covering stone reduced the reflective surfaces within the choir, absorbing more sound. Chanting would be the least affected, as the large number of chanters would produce a significant amount of volume. For soloists intoning the chants, how loud they needed to project was defined by their immediate material surroundings, with the fabric outlining how far their sound needed to reach. Polyphonic singers standing at the altar steps would have a different experience than when they sang in the center of the choir due to their proximity to the draperies, silks, and carpets surrounding the altar, which would dull their immediate aural feedback. Within the center of the choir, the singers would have had more distance between themselves and absorbent materials, perhaps enabling them to better hear the entirety of the space. For singing that produced less volume, the singers' location relative to the materials would change their aural feedback within the space.

Within the new choir, aural feedback would change as procession routes began to take singers through their new space. Processions were a regular part of the celebration of mass as bodies moved between altars, through the choir, and on big feast days through the city and between Notre-Dame and its surrounding churches.[312] On feasts of duplex or annual rank, procession occurred after Vespers as well as before the

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[312] Rebecca A. Baltzer, "The Geography of the Liturgy at Notre-Dame of Paris" in *Ars Antiqua: organum, conductus, motet,* ed. Edward Roesner (Farnham: Ashgate, 2009), 59-78. Roger E. Reynolds, "The Drama of Medieval Liturgical Processions," *Revue de Musicologie* 86, no. 1 (2000): 127-142. Margot Fassler, *The Virgin of Chartres: Making HIstory through Liturgy and the Arts* (New Haven: Yale University Press, 2010), 133-323.

Magna missa, or the large mass of the day held in the afternoon.[313] As an active part of worship, processions varied in length: the path the chapter took with processions on major feast days taking them out through the city, while smaller processions could occur within or just around the cathedral. The new choir presented plenty of open floor space with the central aisle, and through the hemicycle, however the wall at the western end limited possible navigation within the enclosed space. Leaving and reentering through the wooden wall was only possible if doors were put in place to ease the movement and access of the chapter.[314] The gallery is also believed to have been accessible through narrow staircases within the choir, enabling slow movement into the upper aisle.[315] Processions moved singers from under the central vaults, through the side aisles and galleries, and often out of the choir and cathedral entirely.

While processing, the chapter chanted, moving slowly to the next destination. Polyphony wasn't sung while processing, but it could be used before and after the procession moved, to frame the experience. As such the polyphonic singers also had to adjust to their new location, and new spatial relations to one another. Moving and repositioning can change the proximity, and perhaps the order in which singers stood, which Potter indicates can have effects on tuning, blend, and balance between singers in response to changes in what they hear from other voice parts.[316] Moreover, as singers processed, singing beneath the shorter vaults of the side aisles, only 10 meters tall, would provide more immediate aural feedback than beneath the main vaults. Both

[313] Wright, *Music and Ceremony*, 103.

[314] Doors to the center and each side aisle of the choir in 1182 can be seen in Tallon and Sandron's images of this stage of construction. Tallon and Sandron, *Notre-Dame*, 44-45.

[315] Erlande-Brandenburg, *Notre-Dame*, 46.

[316] Potter, "Ensemble Singing," 164.

the vaults and the exterior walls would be closer when processing through side aisles of the arcade, and through the gallery. When moving through the gallery, sound would additionally reflect from the partial walls created by the arches separating the gallery from the choir. Additionally, the concentration of bodies would be greater in this location, allowing chanters to better hear each other, but also deadening the space. The experience of singing changed with each stop and new location, as the concentration of sound shifted depending on vault height, and type of singing.

Sounding along with the daily singing practices was the onslaught of construction noises singers of daylight services had to learn to mitigate or ignore. Services before or after sundown including matins, lauds and only in some seasons vespers, and compline would not be affected by construction as the workers would have stopped their work for the day when the sun went down. It's also very plausible that construction would have been halted for feast days of at least Duplex rank and above so that the occasion would be uninterrupted. However, from Trinity Sunday to the Feast of the Assumption, the months of June through August, services for matins and lauds were held at 6pm the evening before the feast day; meaning that they, too, may have been subjected to construction noises.[317] For prime, terse, mass, and sext construction noises would always have been in full force. Sounds including hammering and carving of stone, the thunk of stone being put in place, and shouts were to become the accompaniment to singing.[318] The wooden wall would have done little to dull the outside noises for those within the choir, with the possible exception of muffling human and animal-made noises

[317] Wright, *Music and Ceremony*, 103. During the summer months, Paris has long daylight hours lasting on some days from 6:00am to 10:00pm. https://www.timeanddate.com/sun/france/paris?month=7

[318] Pierre Du Colombier, *Les Chantiers des cathédrales: les trésoriers, les architectes, les maçons, les sculpteurs d'après les textes, les miniatures, les vitraux, les sculptures* (Paris: A. & J. Picard, 1953).

farther to the west of the building. With afternoon services lasting from noon well into the afternoon, construction wouldn't have been able to pause for that period of the day while still making quick progress. As such, the chapter had to adjust to their new daily accompaniment.

Figure 2.13 Image of Medieval builders. Image credit: Princeton University, *Histoire Ancienne Jusqu'à César,*

Figure 2.14 Image of Medieval masons. Image credit: *Les chantiers des cathédrales*

Noise would have been the most disruptive to solo or small ensemble singing. The volume produced by group chanting, though individuals could have been distracted at the west end, was likely enough to combat construction noises and keep chanters together, though individuals could have been distracted at the west end. The effect of noise on polyphonic ensembles possibly varied depending on the type of polyphony being sung and on the number of singers. The more singers, the more volume, but also, more homorhythmic and homophonic textures such as those of conductus or discant would additionally help produce more sound. Soloists were the most vulnerable to noise, as they had no chance of producing enough volume to mitigate the sounds of construction just outside the choir. These singers, particularly just after resuming worship in the choir, would have needed to be disciplined to keep their focus on loud days. As construction progressed, it is also possible that singers and listeners grew accustomed to the background noise until it became akin to white noise, allowing them to learn to block the noise out to some extent. Until then, singers and listeners alike would have needed focus to sing and listen through services.

The consecration of the altar in May of 1182 allowed singers to acclimate to the new space in a season with few major feasts. Coming into the choir after Easter, but months before the Assumption of the Virgin, chanters and soloists alike would have been able to focus on adjusting their sound with chants and psalms, in variation with some minor feasts. As they gained familiarity with the space, polyphonic singers could then begin improvising, perhaps as they moved into the Christmas season. Each group of singers, including the matins singers, the chapter attendees chanting during Vespers, and polyphonic singers would all have been able to experience the shift into the new choir acoustics. It stands to reason that much of the rhythmic experimentation that characterizes surviving polyphony occurred during the period of construction between 1182-1208 as singers adapted to the new choir and its acoustics.

Addition of the Transept and Nave

Singers had the opportunity to settle into and explore the acoustics of their new choir as construction continued outside the choir. That is, until the interior of the entire cathedral became part of their performance space. Work during the third stage of construction did not directly affect the choir, providing the most stable material conditions possible for singers in the choir. Soloists, chanters, and polyphonic singers alike were able to grow accustomed to the new acoustics, completing at least twenty five full cycles of the liturgical calendar, if not several more. The next change in the size or acoustics of the space occurred with the removal of the choir's enclosing wooden wall at or just after the completion of the third stage of construction in 1208, and the rest of the cathedral became part of the soundscape.[319] It is unclear when the removal of the wall would have been carried out, though it seems most practical for the removal to have happened following the completion of the floor level walls of the nave and western façade to ensure that the cathedral was enclosed and protected. The addition of the transept and nave more than doubled the size of singers' performance space, requiring singers to readjust their listening and sound production. But, in addition to the increased size, the vaults of the west bays had yet to be built, meaning that sound reflections in the bays did not return back down into the nave, creating an inconsistent soundscape. For singers in the choir, this lack may have had a negligible effect on their performance. The incomplete vaults would matter at least temporarily for processions through the nave, or at least up to the bays that lacked vaults, changing the aural feedback for those below. The addition of the transept and nave more than doubled the size of the singers' soundscape.

Singers' aural feedback changed drastically with the absence of the enclosing wooden wall, requiring significant adjustments to sound production. Singers now had to address a much larger volume of space to fill, and to the resonance that occurred both within the choir and that sounded from the nave.[320] Monophonic chanting could once again rely on the strength in numbers in their immediate surroundings not only to

[319] Kimpel, *Die Querhausärme von Notre-Dame zu Paris.*

[320] Resonance and sound reflections caused significant complications in other cathedrals and church spaces historically such as St. Pauls' cathedral in London, San Petronio in Bologna, and San Marco in Venice. See: Howard and Moretti, *Sound and Space,* Appendix 1. Anderson, *RASTI Measurements in St. Pauls' Cathedral*. Schnoebelen, "Performance Practices at San Petronio," 37-55.

produce enough sound within the space, but also to match their volume level, tempo, and pitch while chanting to maintain unity. Soloists, who would already have adapted to the heights of the choir vaults at this point, would continue to be most concerned with projecting only to those listening in the choir, as only the chapter needed to hear them. The soloist would perhaps be tempted initially to sing louder, before returning to largely the same singing technique due to the unsustainability of the extra effort. Especially for the polyphonic singers, the increase of space to fill and the decrease of volume within the choir, might have incited singers to sing louder, straining their voices as they attempted to fill the entire cathedral. Having multiple tenor singers likely took on a new significance as they would have been better able to produce the sound necessary to fill the vaults. Doubling any voice parts in the singing of organum would have had much the same effect, easing the strain on the individual voices. The increase of the cathedral's size could also have been mitigated with the improvisation and performance of three and four-voice settings and use of discant rhythmic textures, which, as noted above, is more frequently documented around the start of the thirteenth century. The sudden increase of size, then, was likely to have posed the most difficult for the polyphonic singers.

Singing could also move beyond the choir at this point to process into and through the newly complete bays. Musicologist Rebecca Baltzer outlines procession paths that took the chapter to altars dedicated to saints (altars that would later be moved into lateral chapels) throughout the choir and nave, processions to the altars in the choir that first circled the sanctuary in the side aisles before re-entering the choir, and processions that visited altars in neighboring churches before returning to

Notre-Dame.[321] After the completion of the nave vaults, movement through the entire cathedral during processions became possible, giving singers access to the length of the nave and the larger number of bays. The addition of the nave and completion of all the vaults allowed singing in every area of the cathedral as use of the cathedral was now temporarily uninhibited.

Processions moved singers through areas with different aural feedback as they traveled through the cathedral. The choir, with its familiar high vaults, would then transition into the transept in which the side aisles temporarily ended, opening into one tall, open space. But with no side aisles, as the procession moved into the nave, there would be a moment for each chanter when his sound was no longer reflecting back to him from the aisle, but instead was drawn up into the heights of the transept until they all reached the nave. Singing and listening within the nave's side aisles, especially once the western end of the cathedral had been completed, also could have varied slightly from the chapter's experience in the choir. At the western end of the nave, the bays meet the western façade in all hard right angles, in contrast to the roundness of the choir's hemicycle. The difference in sound reflection between these two shapes would be subtle, and likely would not have required any performance adjustments, but could nonetheless have changed singers' listening experience as they moved throughout the space. Processions, then, provide an opportunity to refresh, reset, or change the singer and listeners' relation to the physical space and the aural feedback within.

Noise would continue to be an issue for singers both inside and outside of the cathedral. The removal of the wooden wall before the completion of the nave vaults would have made the construction noises from vaulting part of the cathedral

[321] Baltzer, "The Geography of the Liturgy," 59-78.

soundscape. Though, at some point between 1200-1208, construction noises may have diminished or ceased altogether until the next land purchase was complete and work could resume, providing a brief respite from the noise. Singing through the completion of the nave's western bays could have required only some small adjustments in their listening and focus from the singers who were already accustomed to singing through construction. Outside, sculpting of the western facade was still underway well beyond this point. However, the thick external walls of the cathedral likely blocked out the noises from sculpting. As such, the completion of the nave vaults provided a more insulated singing environment.

The completion of the nave vaults meant the establishment of a consistent sonic environment, as the last vaults were in place and reflecting sound. Having the final vaults in place changed the resonance of the interior, if only to a small extent, as sound could now reflect off stone throughout the entirety of the cathedral's walls and vaults. Though far from the choir, it is possible that the singers could, in fact, hear and notice the difference as sound was no longer being lost at the far end of the cathedral. People involved in group chanting in particular could have heard the strength of their chanting ringing through the nave, and resounding in the vaults. Polyphonic ensembles of four or more singers, particularly if singing more rhythmic textures as in conductus or discant, might also have been able to hear the difference, as the sound above them would have a longer-lasting resonance. Having all the vaults in place would have created more uniform aural feedback throughout the cathedral, for singers in the choir and for processions.

Singers had a brief period of reprieve from interior construction and noise following the completion of the nave vaults. For around five years, services could be held unhindered, giving singers the opportunity to adjust to the fully completed space, learning what each texture and chant through the liturgical calendar sounded like multiple times over. This period of stability could have allowed for more sonic experimentation, as the chapter and singers settled into the cathedral space. Polyphonic singers, especially ensembles of four or more, would be able to improvise and experiment with rhythmic textures and how they sounded under the vaults. Processions could use the entire cathedral space, and more guests from outside the chapter could attend services. The completion of the interior space gave the chapter the possibility to actually fill the space, with sound, materials, and people if they desired. The stability of the space was short lived, however, as renovations removed what was already in place to make way for new materials.

Renovations

In the final stage of construction, singers faced a tumultuous performance environment. Over a period of one hundred years, work would start and stop three times as first the windows were replaced and then the lateral chapels added to the cathedral in two waves of construction. These renovations meant the systematic removal of walls, replacement of stone with glass or addition of more space, and movement of construction throughout the cathedral. No specifics are known about how many bays were under construction at any given time, or even if the replacement on one side, or one bay would have been completed before beginning the next. As such, there is no way to gauge how much sound was lost at any given time. Having grown accustomed to a fully enclosed space, the removal of areas of the walls—the loss of those reflective materials—created a new taxation on sound production. Additionally, the removal of the walls in between the singers and the vaults overhead would have drastically altered aural feedback from the vaults, cutting off the reverberation in the choir completely. Enduring around thirty years of work in the choir, after sixty years of work in the nave and transept, may have been the hardest for the singers of all.[322] Renovations would have a direct impact on singing and worship in the choir for the first time since the chapter entered the new cathedral.

To compensate for the alteration of sound reflection, singers would have had to retrain their ears and voice to focus sound within their immediate surroundings. The loss of walls and the absence of those reflections may have caused singers to sing louder as an initial response to the decrease of volume and aural feedback within the choir. The lack of aural feedback in the space made focusing on those singing closest to themselves all the more important, particularly for polyphonic singers. The singers may have grown accustomed to hearing themselves in the completed space in the few years without construction, incorporating the acoustics of the space into their sound even if subconsciously.[323] While they would have been missing the walls, the most important aural feedback is that of your immediate surroundings, which for polyphonic singers would be their fellow singers as they stand in the choir.[324]

Adding the lateral chapels and widening the transept renewed singers' difficulties with opened walls and construction noise within the cathedral. Even before the

[322] The "thirty years of work in the choir" includes the addition of the lateral chapels, from approximately 1296-1320, and an additional 5 years of window replacement starting in 1225.

[323] Potter, "Ensemble Singing," 161.

[324] Ibid., 160-161.

renovations on the windows were completed, walls were being removed to add the lateral chapels. Beginning in the nave, the removal of externals may not have had an immediate effect on singing in the choir, depending on the distance, though it certainly would have affected the sounds of processions. However, the noise very well could have disturbed singing in the choir. The transept was also widened at this time, removing even bigger external walls to increase the size of the cathedral. As the transepts were just outside the choir, the removal of one of these walls would not only produce significant amounts of noise to combat in the choir, but would also drastically reduce the volume and resonance within the choir. Building the lateral chapels in the choir would have had a direct effect, again removing reflective and sound containing surfaces and causing construction noises in close proximity to singers. With the choir stalls in place to the north and south, it's unclear how the loss of the external walls could have affected singing. But, the construction of chapels in the hemicycle removed the only walls enclosing the space to the east, and significant portions of it at once because of the fewer buttresses along the external walls in the hemicycle. With the removal of each new section of wall, the soundscape and loss of vocal volume within the choir changed.

Once again, proximity to the open walls and the number of singers would have changed aural feedback and the singers' experiences. For instance, polyphonic singers standing at the altar steps while the hemicycle was under construction would receive little, if any sound reflection from the choir space. As with the removal of the windows, singers' most important feedback remained in their immediate surroundings (a listening practice to which they would have already adjusted). With the open walls on the same elevation as the singers, the loss of resonance may have had a more immediate impact. To mitigate the negative effects, they could have used rhythmic textures that increased sound production and articulation. For instance, singing in four-voice discant textures would produce more sound, which could be used to try to overcome the missing walls and still fill the choir with sound. Or, conversely singing florid two-voice organum may have been less taxing for singers, who had become accustomed to not filling the choir or the vaults with sound. As such, two-voice organum singers would have already grown adept at only producing enough sound for the chapter to hear them, minimizing the effect of the missing walls and putting less strain on their voices. The sound reflection of the vaults would likely have required a larger amount of sound production present only in group chanting, or maybe polyphonic settings with six singers depending on how many walls were missing at a time. The missing walls would have affected all singing within the choir during construction.

Additionally, work would be directly behind and infront of a different group of singers as construction moved around the choir, changing their experience within the space. The removal of the walls still would have had an effect on listening in particular. Construction directly behind or infront of a section of singers could shift their focus to the construction, to the sight of the missing wall and the alternative source of noise. Even outside of construction hours, soloists and chanters sitting in front of the missing walls received different aural feedback than those in front of a wall, changing their listening experience, if only slightly. The movement of construction would have altered the way chapter members listened and sang, particularly due to their proximity to construction noise.

Noise would have had a significant impact as the stone work to build the chapels was even closer to where the chapter sang, with no sound barrier in between them and construction. This time, the removal of walls was on the floor level, putting stone work in direct competition with singing over a prolonged period of time—even longer than the replacement of the windows. Noise would once again affect daytime services, likely forcing singers to project their voices more strenuously, or to double all solo singing for the chapter to be able to hear and stay unified through construction sounds. For chanters to continue to stay together they would also need to continue to focus on listening to their immediate surroundings, so as to stay with the singers on either side of them. Each time construction moved to a new bay, listeners and singers alike had to mentally re-adjust to account for the change of sound source. This may have also affected singer placements, as the soloists could move farther east or west so as to not stand directly in line with construction and be better heard. However, changing locations would not have mitigated the overall noise, perhaps making it the most significant issue during renovations.

The present discussion of singers and materials conditions could very well continue into the fifteenth century, to include the additions of the stone *jubé* in the choir in 1350 or the wooden *jubé* that completely enclosed the choir in the 1400s.[325] Additionally, this discussion could be infinitely expanded to include the variations of chant singing and polyphonic repertoires throughout the liturgical calendar in great detail. However, with so many unknowns in the construction timeline and no way to better map the construction of the choir with the liturgical calendar, the broad considerations of construction and soundmaking during services are sufficient to

[325] Wright, *Music and Ceremony*, 9 & 339. For a further discussion of the *jubé* see Chapter 4.

provide insight for further thinking on the practical considerations of worship and singing through construction. The singers, succentors, and cantors of the chapter almost constantly had to adapt to a new soundscape or new imposition on singing almost continually for most of a one hundred year period. The construction had to have had a significant effect on the singing practices and repertoire used at the cathedral.

Considering the materials conditions throughout construction alters our understanding of this repertoire and its development in relation to performance practice and the cathedral space. Construction of the cathedral's interior lasted for approximately sixty years, requiring the chapter and its singers to adapt to multiple performance spaces as they transitioned from the old church, to an enclosed choir, the addition of the incomplete nave and then completion of the nave. Each stage of the cathedral's construction produced different material conditions and a different iteration of the performance space that singers needed to adjust to with their placement, volume, rhythm, repertoire, and numbers. The rhythmic development of the repertoire occurring concurrently with that of the construction of the cathedral cannot be coincidental. Yet without considering the material conditions—the changes to the amount of stone, opening and closing walls, and the presence and absence of vaults, wooden walls, and people—and how they affected sound making within the cathedral, our knowledge of the development of the repertoire would be incomplete.

With a significant amount of rhythmic development occurring between 1150 and 1250, the construction history and the incomplete choir must have been a pivotal part of the development of the repertoire. In these one hundred years, the cathedral was under construction or being renovated for all except around twenty years of that time, with ten to thirteen of them being the 1150s, before construction began. The emergence of four-voice settings, according to early mentions, occurs between 1182 and around 1208, when most of the singing was happening within the enclosed choir. The choir space required singers to adjust to the height of the new vaults, the new dimensions, and the contrast of sound reflective and absorbing materials: each affecting the aural feedback during different singing practices. The enclosed choir, then, was central to the development of the repertoire. It is to a detailed analysis of the acoustics of the enclosed choir that we now turn.

Space Sounded: Acoustic Testing and Analysis

The choir of Notre-Dame cathedral was central to musical practices of the late twelfth century. From 1182-1208 it was the only completed section of the new cathedral. As outlined in the previous chapter, the choir, enclosed with a wooden wall to protect and separate it from ongoing construction, was the chapter's worship space and thus the singers' performance space for at least twenty years. The choir was also the primary area in which worship took place. It was just in the choir that early polyphonic development for which the cathedral is known in music history took place. Singers must have known that any difficulties they faced in the choir would be augmented after the nave was added to their performance space. Their time singing in the choir was their opportunity to adapt to the height of the vaults before the enclosing wall was removed. As such, in order to understand polyphonic development at Notre-Dame it is necessary to understand the acoustic environment of the twelfth-century singer's new choir.

To date, musicologists have assumed that the understanding of polyphony at Notre-Dame is based on knowledge of the complete cathedral. Scholars such as Craig Wright write that Pérotin's *quadrupla* settings created "a wholly new sound ideal...one perhaps not out of harmony with the vast...virtually completed cathedral."[326] Thurston Dart also comments that "Pérotin's music, in fact, is perfectly adapted to the acoustics of the highly resonant cathedral (Notre Dame, Paris) for which it was written."[327] However, neither writer expands beyond these statements, nor do they situate Pérotin within the construction history of the cathedral. As modern listeners and musicologists it

[326] Craig Wright, *Music and Ceremony at Notre Dame of Paris, 500-1500* (Cambridge: Cambridge University Press, 1989), 291.

[327] Thurston Dart, *The Interpretation of Music* (London: Hutchinson University Library, 1954), 57.

is difficult to listen “beyond” the recordings made in complete cathedrals and the acoustics we know from the modern Notre-Dame. At less than half the length of the complete cathedral, the enclosed choir would have offered a wholly different acoustic and sonic experience from the complete cathedral. What did the choir alone sound like? What acoustic challenges did the singers face?

In this chapter, I use digital modeling and acoustic simulation to analyze the acoustics of the choir as it might have stood at the end of the twelfth century. The methods of this chapter lie beyond those traditionally used in musicological study. As such, in the following discussion I describe my processes in building the digital model of the choir, running the acoustic simulation with Dawn Schwartz (Masters of Architecture, University of Florida, 2021), as well as the trials and limitations of this project in its current form in detail. I begin by outlining my acoustic methodology including technology available to modern historians, models of how acoustics have been used for historical analysis and previous acoustic tests of Notre-Dame cathedral and why this new testing is necessary. Next, I detail how I built my model of the Notre-Dame’s choir, from the modeling techniques to the evidence on which the model is based. Finally, I explore the acoustic testing process, the modifications made to the digital model, and the results. In this section, I not only list the acoustic results but also reflect on how the acoustic qualities of the choir could have affected sound production and different types of liturgical singing including polyphony and chant.

This chapter also examines the ways in which digital modeling provides a method for reconstructing a historical space and for reconnecting a modern-day researcher with the space under consideration. How does a researcher return to a historical space, particularly when it is no longer standing in its original form? Further, what can we learn about a historical space, its sounds, materials, and acoustics through digital modeling? Digital modeling has, to date, been used by disciplines from archaeology to psychologists to digitize, render, and preserve existing objects or sites, simulate environments and locations, as well as to recreate or reconstruct sites and objects lost to history.[328] A model, then, is a term associated with digital 3D renderings created either from the physical object or site or from the sources and images that preserve information about the object or site. In contrast to a physical space (or object), digital models do not communicate information to the observer in the same manner: looking at the model doesn't represent the size of the space as approaching the physical size would, nor does a model necessarily present the texture of the materials or provide the same forced perspective of an in-person experience (i.e. the observer can navigate a camera angle in the model to observe objects or features from above instead of below).[329] However, a model does enable the reconstruction of, engagement with, and analysis of a space, historical or otherwise, that is not always possible with the physical site. As such, in this chapter, I explore what a digital model of the choir space

[328] Maria Roussou and George Drettakis, "Photorealism and non-photorealism in virtual heritage representation," in the proceedings of the First Eurographics Workshop on Graphics and Cultural Heritage (2001). Glyn Goodrick and Mark Gillings, "Constructs, simulations and hyperreal worlds: the role of virtual reality (VR) in archaeological research," in *On the Theory and Practice of Archaeological Computing,* eds. Gary R. Locks and Kayt Brown (Oxford: Oxbow, 2000): 41-58. Yehuda E. Kalay, "Preserving cultural heritage through digital media," in *New Heritage: New Media and Cultural Heritage*, eds. Yehuda E. Kalay, Thomas Uvan, and Janice Affleck (London: Routledge, 2008), 1-10. Nezar AlSayyad, "Virtual Cairo: an urban historian's view of computer simulation," *Leonardo* 32, no. 2 (April 1999): 93-100. S. Barsanti, F. Gonizzi, and D. Visintini, "3D surveying and modeling of archaeological sites—some critical issues," *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* VII-5/W1 (2013). Osamu Yamada, Yutaka Takase, Ichita Shimodda, and Takeshi Nakagawa, "Significance of digital reconstructions of historic buildings using 3D laser scanner—case study: Prasat Suor Prat Ni tower, Angkor, Cambodia," *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 34, no. 5/W12 (2003): 342-346.

[329] Erike Champion, *Playing with the Past* (London: Springer, 2011). Champion (and others) also discussed the multitude of experiential limitations of digital environments and models and the mediation that happens between the user and the screen—an issue that is also very prominent in the present study.

can reveal about the choir as it might have stood at the end of the twelfth century and its acoustics.

Acoustics: Historiography and Methods

Acoustic testing of historical spaces—either for preserving the space or for the examination of performance and musical repertoires within a given space—has provided new insights for historians' understanding of liturgical performance spaces. Musicologists and art historians alike are investigating the acoustics and soundscapes of cathedrals and churches to discover how the spaces and practices shape each other. Scholars have undertaken investigations of medieval acoustics on multiple fronts, including historiography and the examination of medieval senses, music composition and design, and architecture and on-site acoustic testing of medieval churches and cathedrals. In all cases, the modern science of acoustics has shaped the understanding of medieval experiences of sound and space. As modern historians, acoustics provide one method to temper our modern practices and experiences in historical analysis.

The acoustic measurements and methods that I employ in this chapter are the result of scientific innovations of the twentieth century. With the invention of sound producing and capturing technology, acousticians of the mid and late-twentieth century were able to transform the study of acoustics. This allowed acousticians to gain a deeper understanding of sound's behavior within spaces of different sizes, shapes, and materials.[330] The development of technology including microphones, speakers, and computers enabled more controlled measuring of sounds within a space. Computerized

[330] Emily Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900-1933* (Cambridge: MIT Press, 2002), 90-169.

sound production (speakers), capture (microphoness), and measurement (the computer and acoustic softwares) additionally are capable of measuring techniques such as sine sweeps (a frequency sweep that gradually raises the pitch being produced over time) and impulse response readings (the response reading measures the time it takes a short burst of sound at a desired frequency to reach the first sound receiver). The response times of the sound source (speaker(s) or singer(s)) are measured and recorded by a computer processing the sound reception of the microphones placed in various locations throughout the space. The placement of sound receivers, or microphones, is determined to best gather evidence of the listening experience and acoustic properties of the space from multiple vantage points. Using multiple sound receivers throughout a performance space best accounts for the early and late reflections, including echoes and the tails of reverberation, heard in each area of the space. The acoustic testing methods of sine sweeps and impulse response readings create data on multiple frequencies, multiple acoustic variables, and from all sound receiving locations within the space simultaneously when conducted properly. Advances in acoustic technology have also translated methods for producing sound and calculating acoustic values into digital analytical tools for architectural acousticians.

Architectural acousticians have translated the material and acoustic discoveries of the nineteenth and twentieth centuries into analytical methods capable of calculating the acoustic measures and qualities of a space before construction.[331] Acoustic simulation softwares, such as EASE AMGF and Odeon Acoustic Simulation Software, use formulas to calculate the surfaces, the sound absorption and reflection coefficients of the materials within a space, and level of sound production to determine the

[331] Ibid., 90-169.

performance space's multitude of acoustic features.[332] Through testing and simulation, architectural acousticians are able to measure how the materials, shape, size, and number of reflective surfaces affect acoustic qualities such as reverberation, clarity, warmth, and listener envelopment. The tools and technology created for acousticians (architectural or otherwise) provide methods for testing both live and digital spaces.

Acoustic measurement is now being used by academics, including musicologists and architectural and art historians to conduct further research on historical performance spaces, particularly churches and cathedrals. The modern technology and modes of research in these studies is still based on, and informed by medieval uses of the space, liturgical and musical practices, and listening practices. For instance, in musicologist Vasco Zara's studies of acoustics and music design, he investigates the implications of medieval music theory and theological principles on architectural design and musical composition.[333] Zara uses textual, architectural, and musical analysis to explore the relationship between sound, space, and acoustics to investigate spaces including Castel del Monte and French cathedrals with acoustic pots such as Amiens and Noyon cathedrals.[334] Further, in *Icons of Sound*, Bissera Pentcheva examines the acoustics, design elements of the church, and music design to create a correlation

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[332] EASE AFMG: https://ease.afmg.eu/index.php/software-new.html. Odeon Acoustic Simulation Software: https://odeon.dk/about/about-odeon/

[333] Vasco Zara, "Musique et Architecture: théories, composition, théologie (XIIIe-XVIIe siècles)," *Bulletin du centre d'études médiévales d'Auxerre* 11 (2007). https://journals.openedition.org/cem/1178.

[334] Vasco Zara, "Music, Architecture, Proportion and the Renaissance Way of Thinking," *European Review* (2020): 1-16. Jean-Christophe Valiere, Benedicte Bertholon-Palazzo, Pauline Carvalho, Estele Dupuy, David Fiala, and Vasco Zara "The Contribution of Human Sciences to the Interpretation of the Use of Acoustic Pots in France and in Bordering Countries from the 12th to the 17th Century," *The Journal of the Acoustical Society of America"* 141, no. 5 (2017): 37-74.

between theological concepts, visual aesthetics, and melody in chant.[335] Scholars including Deborah Howard, Laura Moretti, and Sharon Gerstel and Chris Kyriakakis use on-site acoustic testing to examine how performance practices and music are shaped by acoustics and architectural changes. Howard and Moretti combine impulse response, live performance of polyphonic and monophonic settings, audience feedback, and analysis of varying sound sources within the space to examine the relationship between acoustics, architecture, and music in several churches, monasteries, and cathedrals in Italy.[336] Gerstel, Kyriakakis, and team not only combine acoustic testing and live performance, but also use architectural features and embellishments, such as wall paintings to inform the placement of sound receivers in their study.[337] Though Gerstel, Kyriakakis, and their team had to combat later changes to the churches' architecture, they discovered the murals depicting music in the churches were located at some of the best places to listen to worship. Both Howard and Moretti and Gerstel's studies combine acoustic measurement and analysis of live performance in order to conduct a more holistic analysis of sound within a church or cathedral. Studies such as those discussed above have set the standards for acoustic and musical investigation of historical spaces

[335] Bissera Pentcheva, *Aural Architecture in Byzantium: Music, Acoustics, and Ritual* (London: Routledge, 2018). Bissera Pentcheva, *Hagia Sophia: Sound, Space, and Spirit in Byzantium* (University Park: The Pennsylvania State University Press, 2017). Bissera Pentcheva, *Icons of Sound* (New York: Routledge, 2021). It should be noted that Pentcheva's research has been met with some objections and concerns. For instance, the acoustic testing conducted in the *Icons of Sound* project at Hagia Sophia only consisted of a few balloon bursts, the results of which were used to digitally recreate the acoustics of the church. Additionally, the project uses, now, only two case studies to draw larger conclusions about the relation between acoustics, aesthetics, and music in Byzantium and Southern Italy.

[336] Deborah Howard and Laura Moretti, *Sound and Space in Renaissance Venice: Architecture, Music, Acoustics* (New Haven: Yale University Press, 2009).

[337] Spyridon Antonopoulos, Sharon EJ Gerstel, Chris Kyriakakis, Konstantinos T. Raptis, and James Donahus, "Soundscapes of Byzantium," *Speculum* 92, no. S1 (2017): S321-S335. Sharon EJ Gerstel, Chris Kyriakakis, Konstantinos T. Raptis, Spyridon Antonopoulos, and James Donahue, "Soundscapes of Byzantium: The Acheiropoietos Basilica and the Cathedral of Hagia Sophia in Thessaloniki," *Hesperia: The Journal of the American School of Classical Studies at Athens* 87, no. 1 (2018): 177-213.

though they are certainly not the full extent of the studies available. Indeed, multiple studies of acoustic pots in French cathedrals have been conducted, as have many acoustic studies of the speech clarity in churches, and many digital projects of medieval and early modern soundscapes have been created.[338] Each of the aforementioned studies combines acoustic knowledge with historical knowledge on music and performance practice to deepen our understanding of performance practice or musical practices at different churches and cathedrals. These studies use what is known to supplement what is unknown about music, listening, and performance practices in their performance space.

The present study is informed by those discussed above, that laid the foundation for testing methods to use, acoustic features to consider, as well as how to use acoustic testing to further knowledge of historical performance practice in Notre-Dame of Paris. No records exist indicating that Notre-Dame was built to produce a specific sound, however this does not mean that a specific soundscape and quality of sound were not desired (as discussed in chapters one and two). Though the present study will not include the same depth of acoustic testing as those discussed above—primarily

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[338] Andrew Tallon, "L'Espace Acoustique de L'Abbatiale de Saint-Germain-Des-Prés" in *Saint-Germain-des-Prés Mille ans d'une abbaye à Paris*, eds. Roland Recht and Michel Zink (Paris: Académie des Inscriptions et Belles-Lettres, 2015): 135-148. Andrew Tallon: "Acoustics at the Intersection of Architecture and Music: The *Caveau Phonocamptique* of Noyon Cathedral," *Journal of the Society of Architectural Historians* 75, no. 3 (September, 2016): 263-280. Valiere, "The Contribution of Human Sciences." Benedicte Betholon-Palazzo and Jean-Christophe Valiere, "Archéologie du Son: Les dispositifs de pots acoustiques dans les édifices anciens," http://archeoacoustique.labo.univ-poitiers.fr/presentation-generale/. On Clarity and speech translation in cathedrals: John Anderson and Torben Jacobsen, "RASTI Measurements in St. Paul's Cathedral in London" *Bruel & Kjaer, Application Note, BO (1985): 116-121.* Antonio P Carvalho, "Relations between rapid speech transmission index (RASTI) and other acoustical and architectural measures in churches" *Applied Acoustics* 58, no 1 (1999), 33-49. J.S. Anderson and M. Bratos-Anderson, "Acoustic coupling effects in St. Pauls' cathedral, London*" Journal of Sound and Vibration* 236, no. 2 (2000), 209-225. Ettore Cirillo and Francesco Martellota, "Acoustics of Apulian-Romanesque churches: an experimental survey" *Building Acoustics* 9, no. 4 (2002), 271-288. Digital projects include: John N. Wall "Virtual Paul's Cross Project," https://vpcp.chass.ncsu.edu/. Mylène Pradoen, "Bretez Project," https://sites.google.com/site/louisbretez/home. Richard Fawcett, "Open Virtual Worlds: St. Andrews Cathedral c1318," https://www.openvirtualworlds.org/st-andrews-cathedral-c1318/.

because the cathedral does not exist in the historical state under consideration here—nor involve any on-site testing, some gaps in sonic and musical knowledge can still be filled by examining sound and musical development within the incomplete choir. In fact, discussing the choir as an individual performance and acoustic space will allow for many new inquiries to be made.

Additionally, the present study is enlightened by acoustic studies of the contemporary live cathedral. To date, only four published acoustic studies have been conducted of the space. Two of the four acoustic studies do not include their measurement protocol information and are therefore under lesser consideration here.[339] Acoustic studies, the first from 1987 and second from 2015, tested the reverberation time within Notre-Dame cathedral. The 1987 acoustic test conducted by Castellengo, Fabre, and Vivie used balloon bursts to reveal reverberation times of the cathedral as it stood. The 2015 study, conducted by Postma, Katz, and their team, used both balloon bursts (to retest the 1987 results) and sine sweeps to reveal changes in reverberation and clarity. Postma and Katz hypothesize that the differences they found in reverb and clarity were due to the addition of carpet and two chapels added to the cathedral in the 1990s.[340]

[339] Loïc Hamayon, *L'Acoustique des bâtiments* (Paris: Le Moniteur, 1996). Reverberation times listed as: 8.5 (125Hz), 8.0 (250 Hz), 7.5 (500 Hz), 6.0 (1000 Hz), 4.5 (2000 Hz), 2.7 (4000 Hz). Denis Mercier, *Le livre des techniques du son* 4th ed. (Paris: D. Dunod, 2002). Reverberation times listed as: 8.5 (125 Hz), 8.2 (250 Hz), 6.5 (500 Hz), 6.2 (1000 Hz), 4.7 (2000 Hz), 2.5 (4000 Hz). It should be noted that I had access to only 1 of the four studies (Postma and Katz) due to the other three studies only being available in French libraries and archives.

[340] Bart N.J. Postma and Brian F.G. Katz, "Acoustics of Notre-Dame cathedral de Paris" presented at 22nd International Congress on Acoustics (Buenos Aires, 5-9 September, 2016), 5-6.

Frequency band (Hz)	Mean T20 (s) and SD						Mean EDT (s) and SD					
	Balloon burst 1987		Balloon burst 2015		Sine-sweep 2015		Balloon burst 1987		Balloon burst 2015		Sine-sweep 2015	
125	9.93	0.39	-	-	-	-	9.20	0.89	8.34	1.11	8.57	1.17
250	9.62	0.30	8.22	0.18	8.41	0.32	8.75	1.03	7.95	0.93	8.20	1.01
500	7.93	0.23	7.58	0.20	7.38	0.18	7.59	0.93	7.19	1.07	7.42	0.94
1000	6.56	0.29	5.89	0.21	6.08	0.24	6.25	0.85	5.86	0.75	6.14	0.83
2000	5.04	0.21	4.69	0.16	4.61	0.18	4.86	0.69	4.73	0.63	4.67	0.70
4000	3.25	0.22	3.13	0.19	3.04	0.20	3.06	0.46	3.07	0.51	3.20	0.64
	Mean C50 (dB) and SD						Mean C80 (dB) and SD					
125	-5.12	2.48	-6.98	2.84	-3.75	5.08	-4.26	2.53	-5.95	2.97	-2.44	4.74
250	-6.22	4.38	-8.28	2.81	-7.60	3.46	-4.95	4.02	-6.97	2.71	-6.32	3.27
500	-7.40	3.09	-8.08	2.81	-8.03	3.41	-6.17	2.90	-6.64	2.69	-6.56	3.18
1000	-6.33	2.94	-7.23	3.05	-7.18	3.81	-5.02	2.75	-5.64	2.86	-5.67	3.57
2000	-6.07	3.00	-6.27	3.31	-7.04	4.16	-4.68	2.95	-4.67	3.14	-5.38	3.89
4000	-3.90	2.55	-4.09	3.11	-4.21	4.55	-2.25	2.51	-2.36	2.95	-2.46	4.40

Table 3.1 Means from 1987 and 2015 Notre-Dame Acoustic Studies [341]

Table 3.1 presents the findings from the 1987 and 2015 acoustic studies.[342] In both studies, balloon bursts are used for one set of measurements, with the 2015 study also adding sine-sweeps for further measurement. Both studies measure four acoustic features, Reverberation (T20), Early Decay Time (EDT), and two values of Clarity (C50 & C80) at six different frequencies organized from lowest frequency/pitch (listed first) to highest (listed last, seen in the left-most column, frequencies also coordinate to pitches in different vocal ranges as will be demonstrated below).[343] Alongside each acoustic measure (such as T20 or EDT) is the Standard Deviation (SD), which measures the

[341] The 2015 study states that their 125Hz data for T20 was "limited due to poor signal to noise ratio." Postma and Katz, "Acoustics of Notre-Dame," 4.

[342] The 1987 study burst multiple balloons from two different positions in the cathedral, with 13 omni-directional mics spread through the choir, transept, and nave to record the bursts. The 2015 study captured one balloon burst and multiple sine sweeps from 4 locations, with 16 omni-directional mics, half of which were moved between sweeps. No information is given as to how the balloons were burst in either study. Maps of where the microphones and bursts were placed for testing can be found in Postma and Katz, "Acoustics of Notre Dame cathedral," 3.

[343] Reverberation, Early Decay Time, and Clarity are all further defined and discussed below. See "The Results."

margin of uncertainty or error between the mean calculation and each measurement of the test (each value would have been measured multiple times). Both T20 and EDT are measured in seconds, while C50 and C80 are measured in decibels (dB). Both T20 and EDT measure the rate that sounds decay, while C50 and C80 measure the comprehensibility and intelligibility of individual sounds within the cathedral.

As seen in the table above, the reverberation times for the lower frequencies are long, between seven and nearly ten second at 500 Hz and below. Additionally, the clarity values (C50 &C80) are low overall, though in the lower frequencies significant variation can be seen between the balloon bursts and sine-sweep results. The 2015 study by Postma, Katz, et al. shows a distinct shift in clarity between 125 and 250Hz, but closer values between 250 and 500Hz. These measures are more impactful when translated to pitches and vocal ranges, seen below. The acoustic studies of Postma, Katz, et al. provide information about the completed cathedral, and the reflection of the limestone and marble surfaces. However, the decreased air volume and size within the choir alone will yield vastly different acoustic results.

The approximate translations from hertz in the acoustic tests to approximate pitch and octave can be seen in table 2. The pitch and octave have then been transposed back into frequency measured in hertz so as to better orient and approximate the testing frequencies.[344] Further, the frequencies and pitch ranges can be understood through approximate modern vocal ranges. The male vocal ranges, defined by average pitch and octave ranges for modern choral singers are: E2-D4 for bass,

[344] The translation of Hertz to pitch emphasizes the sharp contrast between acoustic technology and pitch in relation to musical scales. The translation of one to the other could not be more awkward.

G2-G4 for baritone, and C3-A5 for tenor (seen below in Fig. 1).[345] Though there is more work to be done in translating the melodic ranges found in the Notre-Dame repertoire and vocal range, many of the polyphonic melodic ranges occupy the tenor and baritone ranges.[346] Notre-Dame may also have had high tenor singers and some countertenors, a vocal range that can extend up to E5 for a slight extension of melodic range.[347] The choir boys (boy sopranos) singing at Notre-Dame would have had a similar to the soprano range of c4-c6.[348] As such, the measurements most important for the purposes of this study are those below 1000Hz.

Figure 3.1 Vocal ranges as they correlate to staff notation and pitch range. Image credit: Smith and Sataloff, *Choral Pedagogy* Third Edition, 230.

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[345] Brenda Smith and Robert T. Sataloff, *Choral Pedagogy* Third Edition (San Diego: Plural Publishing, 2013), 233.

[346] This can be seen in the melodic ranges notated in the Florence Manuscript and W1. This is an area I intend to further investigate and compare in a future iteration of this project.

[347] Peter Giles, *The History and Technique of a Counter-tenor: A Study of the Male High Voice Family* vol 1 (London: Scolar Press, 1994). Steven l Rickards, *Twentieth-Century Countertenor Repertoire, A Guide* (Lanham: The Scarecrow Press, Inc., 2008).

[348] Smith and Sataloff, *Choral Pedagogy*, 232.

Frequency (Hz) in 1987/2015 Studies	Pitch Approximation and Octave Range	Frequency of Pitch(es)
125	B2	123.47
250	B3	246.94
500	B4	493.88
1000	B5/C6	987.77/1046.50
2000	B6/C7	1975.53/2093.00
4000	B7/C8	3951.07/4186.01

Table 3.2 Frequency to Pitch Comparison

As the incomplete choir no longer exists in its medieval form, analyzing the acoustics requires digital methods for multiple reasons. First, completing an onsite study of the Cathedral is no longer possible due to the April 2019 roof fire. The fire caused extensive damage to the roof, vaults, and interior of the cathedral, causing access to Notre-Dame to be completely shut off for the foreseeable future.[349] Recent news indicates that scaffolding is in place to stabilize the cathedral and scientists are now preparing for some early studies of the cathedral, meaning it will be many years before the cathedral is accessible to the public.[350] Second, even if on-site testing were

[349] "Notre-Dame fire: Paris surveys aftermath of cathedral blaze" BBC News, London, UK: BBC (April 16, 2019). Nicolas Vaux-Montagny and Sylvie Corbet, "Fire-ravaged Notre Dame now stabilized, firefighters leave," AP News, New York City, NY: AP, April 19, 2019. https://apnews.com/92db19558da04f09b94cc31fb5ce16a5.

[350] Christa Lesté-Lasserre, "Scientists are leading Notre Dame's restoration — and probing mysteries laid bare by its devastating fire," *Science Magazine* (March 12, 2020), https://www.sciencemag.org/news/2020/03/scientists-are-leading-notre-dame-s-restoration-and-probing-mysteries-laid-bare-its. Francesco Bandarin, "Notre Dame enters a new and high risk phase in its restoration: A huge forest of scaffolding, fused by the fire in April, has to be cut away," *The Art Newspaper* (December 30, 2019), https://www.theartnewspaper.com/news/notre-dame-enters-a-new-and-high-risk-phase-in-its-restoration. Francesco Bandarin, "It's Official: the new Notre Dame will look like the old Notre Dame" *The Art Newspaper* (August 5, 2019),https://www.theartnewspaper.com/analysis/it-s-official-the-new-notre-Dame-will-look-like-the-old-notre-dame. Matt Hickman, "Restoration work resumes at Notre Dame but spire replacement plans remain at a standstill" *The Architect's Newspaper* (May 8, 2020), https://archpaper.com/2020/05/restoration-work-resuming-notre-dame-spire-plans-halted/. See also:

possible, there is no way to test the acoustics of the specific acoustic environment the music in question was performed within. Testing just the choir would require the insertion of a wall, which would hinder and disrupt current worship practices, not to mention require extensive permissions I would be unlikely to obtain. As such, the present study can only be informed by previous acoustic tests and past onsite listening experiences.

Further, testing a space of comparable size would also not result in accurate results. The incomplete choir that stood at the end of the twelfth century is acoustically different from a space intended to be that size, as the fourth wall being made of wood instead of stone produced drastically different acoustic properties. Testing a completed historical or more modern church of a similar size would also provide uncomparable results. In a historical space, the fourth stone wall would create a longer reverberation time for sound. To imitate the wooden wall acoustic paneling could be used, but even that wouldn't accurately reflect the thinness of Notre-Dame's enclosing wall and would thus produce different acoustic results. In modern spaces, the materials, including wood, plaster, and drywall, are too sound-absorbent to match the reverberation of a stone space. As such, testing a digital model of the choir will provide the most accurate acoustic measure of the size and materials of the twelfth-century structure.

The model and the results of acoustic testing of the present study should be viewed as a working hypothesis—the results of what can be known at this time, with the tools available to me, based from archival documents and informed choices for aspects that we have little or no information about. As mentioned, the 2019 fire has prohibited

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Emily Conover, "How to restore the legendary acoustics of Notre Dame," *Science News* (January 12, 2020), https://www.sciencenews.org/article/notre-dame-cathedral-fire-legendary-acoustics-restoration.

any on site research, affecting my ability to gather and confirm several measurements for the digital mode. Additionally, having to build the digital model manually (as opposed to through a laser scan) raised a large number of questions about individual features of the choir of Notre-Dame. During the modeling process, I had to examine how each individual piece of architecture connected, its size and positioning, and how to create the correct geometry in each object to replicate the extant architecture. Further, the work and research presented here are the first steps in examining the acoustics of the choir of Notre-Dame as it might have stood at the end of the twelfth century. As such, this research is a preliminary offering in how digital tools, including digital modeling and acoustic simulation can be used to reconnect with historical performance spaces and repertoire. As will be detailed below, modeling and acoustic simulation require new questions to be asked of the performance space and musical practices, shedding new light on not only the relationship between sound and space, but also on how we examine historical repertoires. While a long term goal of the project is to increase the accuracy of the model and complete further testing, one of this project's contributions—opening new sound-based, acoustic, and singer-focused modes of examining a historical repertoire that has been examined predominantly through text-based methods up to this point—is demonstrated by the research below.

In what follows, I outline how evidence-based speculation informs the modeling and testing processes in the narrative below, while additionally acknowledging the advantages and drawbacks of these decisions. However, the core of the acoustic analysis is based on the simulation results. This acoustic testing and analysis provides analytical evidence on how sound likely behaved and responded to the materials within the choir of Notre-Dame. Below I detail the modeling methods and decisions made in my digital modeling of the Notre-Dame choir space in the twelfth and early thirteenth century. I additionally outline the possibility and preventative measures for countering human error, as well as the distinction between creating a reconstruction of the cathedral versus building an acoustic model and how that changed some of my approach to modeling the choir.

Building the Digital Model

My method for digital modeling comes from methods and techniques developed by the Venice Charter, London Charter, and Meredith Cohen and the "Paris, Past and Present" team including Anthony Caldwell, Gabrielle Chitwood, Tori Schmidt, and Kristine Tanton.[351] The "Paris, Past and Present" team has offered me both personalized help and access to modeling tutorials. Cohen and team developed a number of methods and techniques to build the geometry and architectural features of Gothic architecture from scratch within Vectorworks, a modern architectural software. The tutorials for Vectorworks cover topics such as building square and rectangular vaults, ribs and arch profiles, and measuring and scaling the floorplan. These tutorials offered me the base skills adaptable to model the features of Notre-Dame of Paris. I also draw on Cohen and team's best practices for constructing features with unknown measurements or positioning. In what follows, I outline the construction of my digital model and the process and sources used to inform my decisions.

[351] The Venice Charter for the Conservation and Restoration of Monuments and Sites, 1964, https://www.icomos.org/charters/venice_e.pdf. The London Charter for the computer-based visualization of cultural heritage, 2006, https://www.londoncharter.org/introduction.html. Meredith Cohen, "Paris, Past and Present," University of California, Los Angeles. http://paris.cdh.ucla.edu/

Here, I should also note that my model differs in function and appearance from those of the “Paris, Past and Present” project. Because I am building a model for acoustic measurement and not to recreate the space as it might have stood, I have, with consultation from Chris Kyriakakis, an electrical engineer who specializes in psychoacoustics at USC, omitted sculptural elements and some of the more decorative features from the model imported for acoustic testing.[352] The primary function of my model is to be leak proof (meaning that no sound escapes or moves through gaps in what should be walls or windows), to have all the materials in place, and to have the dimensions as close to accurate as possible. Building the individual features—such as the arches with decorative and functional profiles, ribs in the vaults, capitals and plinths—necessary to recreate the cathedral as exactly as possible means hundreds of individual pieces that need to be perfectly aligned, positions, and sized. Each individual piece provides an opportunity for small, difficult to detect gaps to develop, allowing sound waves to leak and escape through the gap. The individual elements create even more opportunities for overlapping materials and objects, which is an equal concern for the model to be processed and read correctly in the acoustic software. As such, following modeling practices suited to acoustic models, aesthetic and structural elements including vault ribs, correct capitals, arch profiles, and responds have not been included in the acoustic model.[353]

The adaptation of a digital model to suit digital methods and analytical aims of the project is an issue of discussion and debate amongst digital humanists. The practice

[352] The smaller sculptural details and crevices would only have affected very high frequencies and are therefore unnecessary for my model. Under the direction of Kyriakakis, and in consulting demo projects from the Odeon: Acoustic Software website (https://odeon.dk/examples/worship-spaces/), I was also encouraged to omit the ribs of the vaults, responds on the walls, and the arch profiles.

[353] Ibid., footnote 24.

of digital modeling, writes scholars such as Diane Favro and Geeske Bakker, is shaped by the information available about the space or site and what the researchers are trying to communicate with the model. The creation of 3D models face significant barriers in terms of having complete and accurate data including every individual measurement, which are often not available or unaccessible. It is the speculation and hypothesizing involved in creating digital models that has caused such debate over the uses and creation of digital modeling.[354] As Favro and Bakker emphasize, scholars working from the same historical evidence, primary documents, and even archaeological studies could produce different models because of the varying interpretations of the historical information.[355] For example, Favro and teams modeling of the Romand Forum within Constantinian Rome, had to combine evidence from Ancient Rome as well as descriptions of Rome from historical periods afterwards, as well as disciplinary disputes between architectural historians and archeologists.[356] Though projects strive for historical accuracy, digital modeling primarily reflects the state of knowledge about a location allowing models to have varying degrees of known and speculated details.[357] The model presents an approximation not a historical duplicate. To visually depict a

[354] Diane Favro, "In the eyes of the beholder: virtual reality re-creations and academia," *Journal of Roman Archaeology* Supplementary Series Number 61 (2006): 324-325.

[355] Decisions have to be made and negotiated for each element and data point under contention, as mentioned by Bakker, Meulenberg and Rode. Geeske Bakker, Frans Meulenberg and Jan de Rode, "Truth and credibility as a double ambition: reconstruction of the built past, experiences and dilemmas," *The Journal of Visualization and Computer Animation* 14 (2003), 161.

[356] Favro, "In the eyes of the beholder," 321-323. The same is also true of modeling Gothic Architecture, as the buildings have been modified and restored throughout history, requiring scholars and the digital modeler to evaluate the structure's history and the evidence being used to create the model. See: Meredith Cohen, "The Lady Chapel of Saint-Germain-des-Prés, 1245-1255," http://paris.cdh.ucla.edu/lady-chapel/. Cohen, *The Saint-Chapelle and the Construction of Sacral Monarch*.

[357] Favro "In the eyes of the beholder," 326.

location and to assist the viewer with image literacy, different practices exist for visually depicting what is certain and what is hypothesized, attaching metadata, and methods for capturing and disseminating the model—each of which affects the viewers engagement with the digital recreation or reconstruction. Digital modeling practices are adapted to each project depending on what is known about the space, and the team and technology involved in creating the model.

My digital model of Notre-Dame was built manually in Vectorworks, an architectural software, with several benefits and drawbacks. Vectorworks was not intended to be used to build Gothic architecture, requiring some idealization and modified building of the space. In contrast to medieval architects and builders who could use mortar to approximate a perfect curve and to fill in small gaps, softwares requires exact geometry and perfectly connected lines to create solids and surfaces. Building in 3D necessitates objects to be aligned and moved on the x, y, and z axis to ensure the exact placement of each piece and connection between items. The alignment must be confirmed at an incredible zoom that reveals even a millimeter or less of open space to ensure a lack of gaps. Additionally, the best practices for modeling Gothic architecture developed by Cohen and the “Paris, Past and Present” team necessitates constructing the geometry without the use of the modern architectural tools included in the program such as the wall tool. The modern architectural tools are aimed at constructing buildings such as houses, offices, and warehouses and automatically encode the information for the materials and specifications of modern building practices. As such, the geometry for all walls, vaults, and arch profiles are modeled by combining and forming different shapes and lines, as will be described below. Additionally, the best practices for manual modeling Vectorworks results in some idealization of the space. For instance, objects or entire bays can be copied or mirrored to duplicate the objects exactly, as I will explain in describing the building of the choir bays. While using mirroring or duplication can reduce some of the aesthetic features of individual bays, it facilitates efficient and consistent building throughout the modeling process. Despite the unavoidable differences between the digital model and medieval cathedral, the model still has the correct dimensions, number of bays, materials, and geometry.

Reading the Floorplan

Before moving into the description of my digital model, I would like to briefly outline some terminology pertaining to digital modeling, Vectorworks, and the labeling and discussion of the floorplan. Each will be used in the discussion below to mean the following:

- Bay: Denoted on the floor plan as the area inside two double lines. Bays are labeled on the floor plan below.
- Elevation: Referring to the vertical levels of the cathedral, Notre-Dame originally had a four-level elevation.
- Height: Referring to vertical measurements not depicted by the floor plan.
- Length: Referring to the measurements that correspond visually with the east to west orientation of the floor plan.
- Mirroring: A Vectorworks tool that duplicates a solid object (including vaults, wall facings, and walls) by “mirroring” the object across a selected line.
- Ribs: Denoted on the floor plan by a single line
- Solids: A 3D object built in Vectorworks. Used to describe constructing walls and enclosing structures primarily.
- Vault segment: The area between ribs and wall facings on the floor plan, the smaller pieces that make up the vault above a bay.
- Wall facings: Denoted on the floor plan by a double line. Wall facings are not complete walls, but are the areas of stone containing arches between

each column that visually and physically divide bays. I use the term wall facing to help mark the difference between external and internal walls.

- Width: Referring to the measurements that correspond visually with the north to south orientation of the floor plan.

The floorplan pictured below is also labeled for ease of discussion. The bays are labeled with numbers in the side aisles (including the hemicycle) and letters in the central aisle.

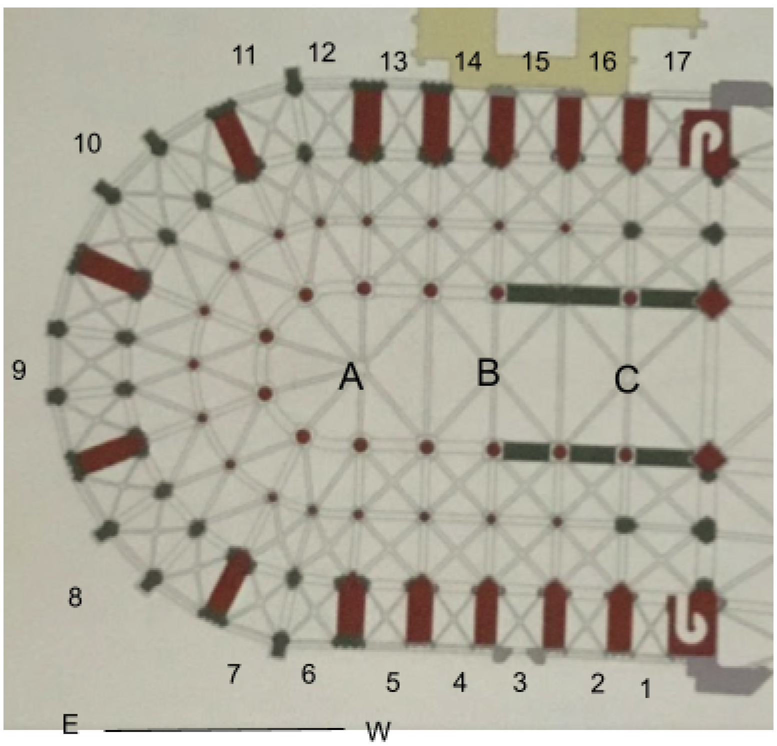

Figure 3.2 Labeled Floor Plan. Plan Credit:Tallon and Sandron, 2013. Please note that this floor plan includes the lateral chapels on the outermost edge of the cathedral and the expansion of the transept, both of which are not constructed in the model.

Ground Level (Lowest level of elevation)

At the foundation of the digital model is a scaled floor plan of the cathedral as it stands today. Multiple versions of Notre-Dame's floor plans exist including those of Marcel Aubert, Alain Erlande-Brandenburg, and Andrew Tallon and Dany Sandron's.[358] I chose to base my model on Tallon and Sandron's floor plan because it is the most recent and the result of a laser scan of the cathedral. To begin modeling, I scaled the image of the floor plan in Vectorworks based on measurements both from Tallon and Sandron's laser scan and from external sources such as the Notre-Dame of Paris' own website and Aubert.[359] The measurements of the choir are largely agreed to be 36 meters long without the aisles, and 36 meters wide including the side aisles.[360] I chose not to begin with the medieval geometric design and translating the medieval measurements (following the guidance of studies such as Liefferinge and Bruzelius) because my model is intended to be a sound model rather than a recreation of the monument. As such, my intention was not to recreate the medieval uilding methods and techniques. After scaling, rescaling, and triple checking the scale with known measurements, the floor plan can then be traced to establish the measurements of each bay, the placement of the columns, and the placement and direction of the ribs in each vault. The floor plan provides a blueprint moving forward.

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358 Marcel Aubert, *La Cathédrale Notre-Dame de Paris: Notice Historique et Archéologique* (Paris: D.-A. Longuet, 1909), 171. Alain Erlande-Brandenburg, *Notre-Dame de Paris*, John Goodman, trans. (New York: Harry N. Abrams, 1998), 40. This floor plan is actually that of Abbé Delagrive from the 18th century that situated the cathedral on the Île-de-la-cité. Andrew Tallon and Dany Sandron, *Notre-Dame de Paris: Neuf siècles d'histoire* (Paris: Parigramme, 2006), 183.

359 Tallon and Sandron, *Notre-Dame*, 183. Aubert, *La Cathédrale Notre Dame*, 56.

360 Aubert, *La Cathédrale Notre Dame*, 56. Erlande-Brandenburg, *Notre-Dame,* 55. Erlande-Brandenburg only provides the width of the center aisle of 41 feet wide, or 12.49 meters.

I began the modeling of the ground level with the rectangular bays in the side aisles of the arcade. The modeling of the rectangular bays of the choir was the easiest and the fastest for me to build. The rectangular, almost square (measuring 7 meters by 6m for bay 1 and 5.25 meters by 6 meters for bays 2, 3, 4, and 5), bays on the north and south sides of the aisles feature four shorter bays and one longer bay at the transition into the transept. The vaults of these bays are 10 meters in height and have wall facings (that combined form the arcade) that are consistent on both sides in regards to size and shape.[361] With the duplication tools available in Vectorworks, only the vaults and interior wall facings of one bay of each size (bays 1 and 2) had to be modeled from scratch. After building the vault over one of the smaller bays, I then used the mirror tool to create an identical version of the vault reflected over a selected point (in this case the edge of the connected bays) to create four identical bays connected to one another.[362] I then built the vault over bay 1 (7m by 6m) of the side aisle to create one complete set of bays. With all five bays modeled and inplace, the vaults could then once again be mirrored and duplicated to create all the vaults in the side aisles. I first mirrored all five vaults to create the double side aisle on one side of the choir, then mirrored the double aisle across the center of the choir (visible on the floor plan at the base of the model) so that identical vaults in the side aisles on both sides of the choir

[361] A previous version of "History" page on Notre-Dame online stated 10 meters (Accessed March, 2017). The webpage's historical narrative likely incorporated measurements as a result of Tallon and Sandron's laser scan, and the information that was shared with the cathedral personnel. Indeed, for a brief period of time the website listed measurements for the cathedral including the height under the main vault (33m), height under the roof (43m), height of the side aisles (10m), length of the transept (14m), length of the choir (36m), length of the total cathedral (128m), length of the west facade (43m), width of the choir (12m), width of the nave (12m), width of the side aisles (12m), and width of the transept (48m).

[362] The mirror tool is only one way to duplicate objects within Vectorworks. I could have also copied and pasted the vault into the next bays. However, the benefit of the mirror tool is that it allows for simultaneous duplication and placement of an object (the vaults in this case). I did double check the placement and connection of each vault to ensure that they were connected in the proper places.

were in place. I followed the same process to put the wall facings in place in the rectangular bays: I built the facings in bays 1 and 2, then mirrored bay 2 in bays 3-4 on one side before mirroring all 5 across the aisle to complete the modeling of the rectangular side aisle bays.

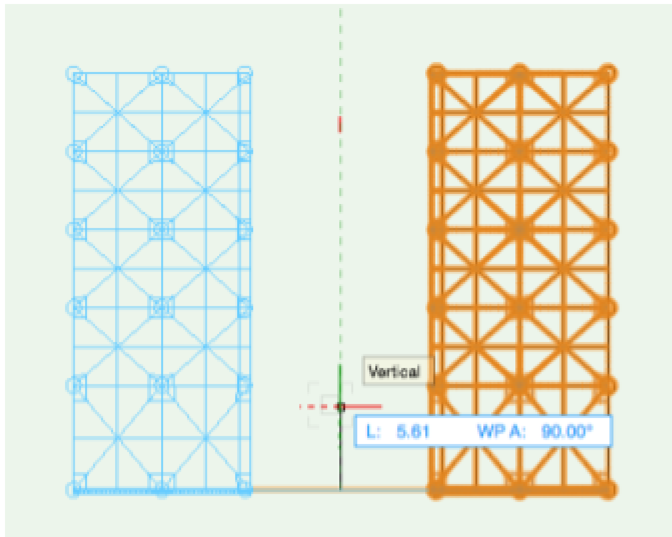

Figure 3.3 Image: mirroring of rectangular side aisle bays. Orange highlight is the build vaults, the blue vaults are those being mirrored. In the center is the tool and the mirroring point at the center of the center aisle. Image Credit: Morgan, Notre-Dame model built in Vectorworks 2019-2020.

The vaults of the hemicycle were the most difficult to construct, as not only does the vaulting change between inner and outer aisle, but everything must be built on a rounded surface making measurements and accuracy more difficult. A close examination of the floorplan indicates slight inconsistencies in the location of the ribs of the vaults on the north and south sides of the hemicycle, and as a result I had to build the vaults of the hemicycle individually. The vaults of the hemicycle vary between inner and outer aisle, and to accommodate the curve of the hemicycle. The number of vault segments is greater in the outer side aisle than in the inner aisle. On the outer edges of the hemicycle (seen in bays 8, 9, and 10 in fig. 2), the larger bays are divided by two ribs in the interior aisle and four ribs in the outer aisle. Additionally, the inner aisle immediately shifts into the angled ribs and vault segments (seen in bays 6, 7, 11, and 12 in fig. 2) to account for the shorter length. The bays of the outer aisle retain the crossed ribs for only these two exterior bays, though at skewed, uneven length to meet at the top of the vaults. To construct these rounded vaults with the correct shape and to match the tools requirements of Vectorworks required some ingenuity.

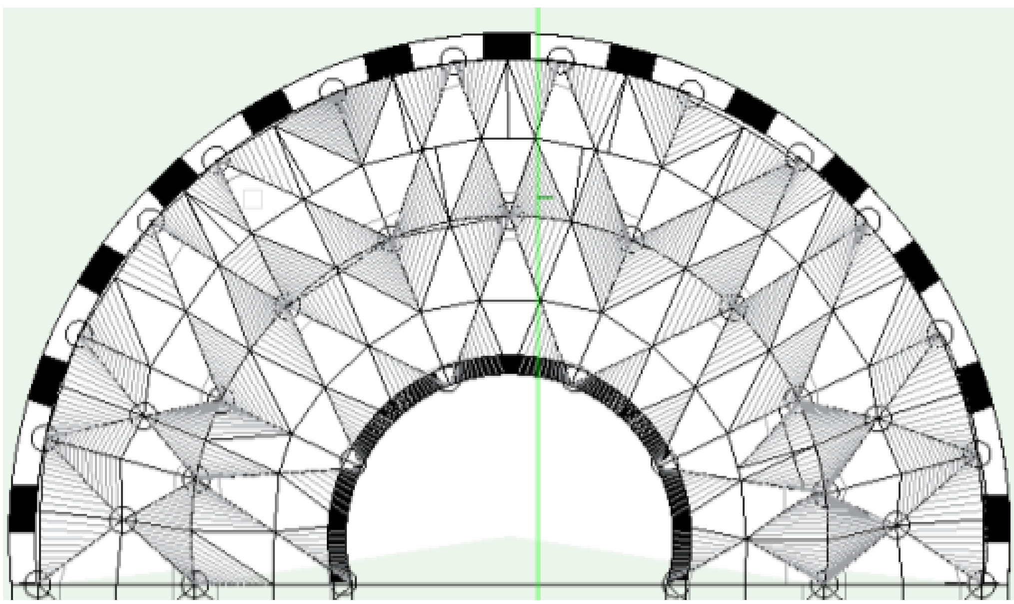

Figure 3.4 Image: wireframe of hemicycle vaults on floor level from top view. Image credit: Morgan, model of Notre-Dame built in Vectorworks 2019-2020.

The construction of the hemicycle vaults relied most prominently on the correct placement and size of the arches of the ribs and the arches that create each bay. To create the vaults of the hemicycle I first drew the lines including the interior, central, and external arches, the lines dividing the bays division and the rib positions. I then used the arch and vault height from the rectangular bays (to which the hemicycle vaults had to connect) to begin building the arches in the hemicycle. Once each arch was complete I then began creating the vaults. In modeling the rounded vaults I had to build with two things in mind: first, that I had to follow the vault segments indicated by the floorplan and second that to create a solid object from each vault segment, the Vectorworks tool Loft Surface required two edges and an intersecting line to create a solid for each vault segment.[363] That is, each vault segment needed to be defined by two arches and a connecting horizontal line segment (the top of the arch in this case, see above). Building vaults with Loft Surface creates individual vault segments connected at the top, as seen in the image above. In several bays (8, 9, and 10 in fig. 3.2), this process left a small triangle of empty space at the top of the vault to accommodate the changing width of the vaults in the outer aisle. To fill this space, I divided the gaps into two smaller triangles to better match the larger vault segments. With the spaces at the top of the vaults filled, the hemicycle vaults were completed.

Building the wall facings of the arcade in the hemicycle was also more difficult than in the rectangular bays. The walls of the hemicycle must be built separately from those of the rectangular bays, and in a stricter order of operations when modeling.[364] To build the correct curve and correct thickness of the wall, the hemicycle is constructed from two rounded arches joined together to form a solid object of the correct dimensions. The visual unity of the cathedral requires the arches of the wall facings in the hemicycle to be the same height as those in the rectangular bays, but with a decreased width produced by the rounding of the hemicycle. The arches of the interior wall facings are all of slightly different width, again requiring each arch to be modeled

[363] Each vault segment has to be a solid, or 3D object in order to be coded with a material and to reflect sound. Once the vault segments have been created using Loft Surface in birail sweep mode (a setting of Loft Surface that requires two sides and a cross section to create the surface), I can then use the Shell Solid tool to create a uniform thickness, as they would if made out of stone and mortar.

[364] The modeling process of Cohen's *Paris, Past and Present* project did not use the Wall Tool in Vectorworks, which is designed/coded for constructing modern architecture. To properly and consistently accommodate walls of varying thicknesses and shapes in Vectorworks, all walls are created from basic geometry and solids (objects, defined by 3D geometry opposed to shapes and lines which are only 2D).

individually before subtracting them from the wall. Once the arch from each bay has been modeled and correctly placed and angled, the arch shapes are “subtracted” or removed from the solid wall to create the arched openings of the wall facings. This process is also necessary to produce the rounded arches of the hemicycle. In the floor level, subtracting the arches from the wall completes the hemicycle wall facings.

Gallery (second level of elevation)

The gallery, the second level of the cathedral’s elevation, runs through the rectangular bays and the hemicycle. The gallery presented a different challenge than the ground level. Confirmed measurements in the gallery are fewer than those in the ground level, meaning that many of the measurements were based on digital measurements and images. Because the floor plan does not indicate alternate measurements between bay sizes in the gallery (nor do images of the cathedral), the length and width of the bays used in the model are the same as those of the arcade. However, unlike the floor level, the height of the vaults is not cited—a measurement of particular importance. Measurements for the height of the vaults, and the arches in the wall facings (both the larger arch overhead and the two smaller arches) are all based on scaled images: a photograph from the cathedral as it stood before April 2019, and a sketch in the case of the vault height, as no specific measurements are available.

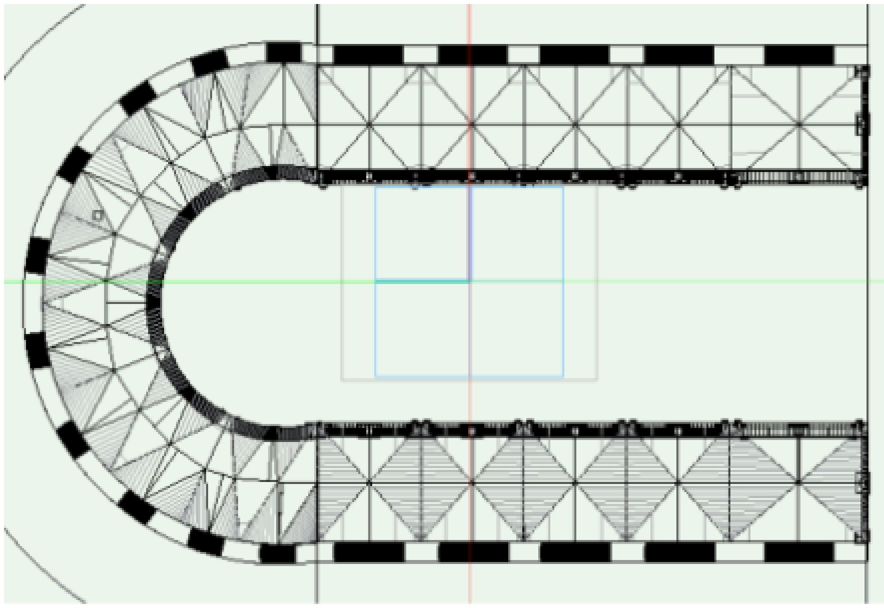

Figure 3.5 Image: wireframe of gallery vaults from top view. Image Credit: Morgan, model of Notre-Dame built in Vectorworks 2019-2020.

To build the gallery, I followed the same process as with the ground level aisles building the rectangular bays first, then those through the hemicycle. I additionally used the mirroring tool for consistency and to reduce error, but again built the hemicycle vaults individually. The wall facings in the gallery are more elaborate than those in the arcade, requiring more individual pieces of geometry to form the whole. Seen in the image below, the wall facings in the gallery feature a recessed larger arch with two smaller arches below. I built the segment of the wall facing with the larger arch and the segment with the two arches as separate solids throughout the gallery (again using the mirror tool in the rectangular bays, as well as copy and paste in the hemicycle to position and angle the arches more accurately).[365] The capitals in the gallery are built from stacked rectangles of alternating sizes to produce the staggered layers of the capitals. I inserted basic capitals in the gallery to add reflective surfaces present in the

[365] In hindsight, there was a more efficient way to build these wall facings out of one solid that I will likely put into place in the next iteration of the model.

gallery wall facings because the slim columnettes of the gallery take up such little room. The gallery, because I had already built the arcade with the same techniques, was the easiest of the levels to model despite having so few confirmable measurements.

Oculus Windows and Above (The third and fourth level of elevation and central aisle vaults)

To complete the vertical construction of the choir's model, I built the walls containing the oculus and clerestory windows and the large vaults above the central aisle. Many aspects of modeling at the upper elevations of the choir required new adaptations to the modeling techniques used at the lower levels of elevation such as the dome-like vaults above the sanctuary, the sexpartite vaults above the choir, and the insertion of windows in hemicycle walls. Building the upper elevations also required me to work with objects of a larger scale than the lower levels, as the central vaults are significantly larger than those in the bays of the side aisles. One advantage in modeling these upper levels, however, is that there are fewer individual pieces to build than in the gallery or floor level making the upper levels faster to complete. Though, many of the features in these upper levels are even more hypothetical than in the lower levels providing a different challenge to the modeling.

The primary challenge of the central aisle vaults was the immense size of each vault. The vertical measurements of the central aisle varies in each study and I was unable to confirm the measurements due to the inaccessibility of the cathedral in Fall 2019. The height of the central vaults is regularly referenced, but with some inconsistency. The sources give measurements ranging from just under 33 meters, to 35 meters: the "Mapping Gothic" project (lead investigator: Stephen Murray), likely based on Tallon and Sandron's laser scan, records a vault height of 32.71 meters, Caroline Bruzelius gives a height of 32.5 meters, Erlande-Brandenburg lists a vault height of 108 feet or 32.9 meters, Hislop lists 111 feet or 33.8 meters, while Aubert provides a measurement of 35m.[366] The height I chose for my model's central vault (up to the top of the vault) is 33m. For the width of the central bays I used a measurement from the laser scan's scaled floor plan (which additionally coincides with the width of the vaults mentioned in Aubert and Erlande-Brandenburg) which indicated the vaults should be 12 meters wide. The length of each half bay corresponded to the lengths of the side aisles seen in the floor plan.

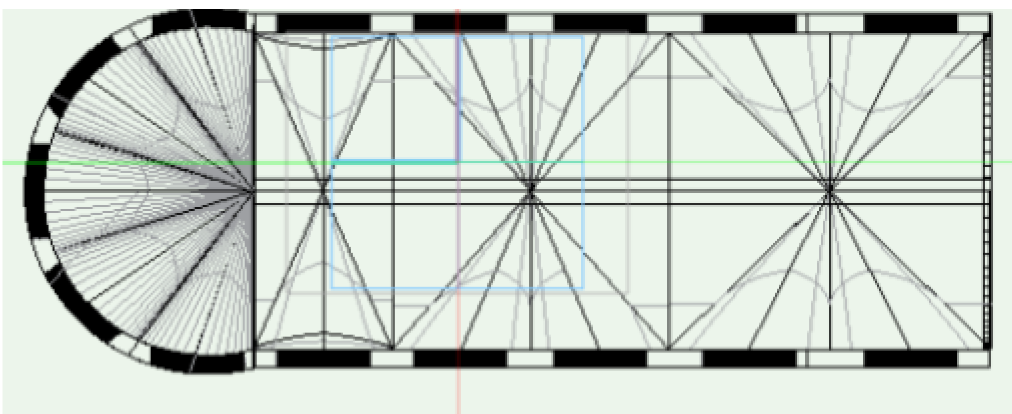

Figure 3.6 Image: wireframe of central aisle vaults from top view. Image Credit: Morgan, model of Notre-Dame built in Vectorworks 2019-2020.

All three vaults of the central aisle had to be built individually. Two vaults of the central aisle (see figure 3.6) are sexpartite vaults, a vault divided into six sections, instead of the quadripartite vaults in the other aisles. The sexpartite vaults have an additional rib that divides the length of the vault (north to south/across the choir). An

366 Stephen Murray, Andrew Tallon, and Rory O'Neill, "Mapping Gothic," Media Center for Art History, Columbia University and Art Department, Vassar College (2010) http://mappingGothic.org/building/1164#/. Tallon and Sandron, *Notre-Dame*, does not give a measurement for the height of the vaults. Caroline Bruzelius, "The Construction of Notre-Dame in Paris," *Art Bulletin* 69, no. 4 (1987): 541. Erlande-Brandenburg, *Notre-Dame,* 55. Malcolm Hislop, *How to Build a Cathedral: Constructing the Story of a Medieval Masterpiece* (London: Bloomsbury, 2012), 60. Aubert, *La Cathedrale Notre-Dame*, 56.

additional central rib not only changes the number of vault segments, but also allows for an additional window to be placed in the external walls. Inserting the extra rib most affects the vault edges to the north and south of the choir (where the windows are located), as they must contain two narrow (compared to the ribs crossing the choir) but still quite tall arches to conform to the vault's overall height. An additional challenge of the vaults above the central aisle is uneven vault sizes. Looking at the floor plan (fig. 3.2), the vault labeled B contains two equal sized rectangular vault halves. However, in order to stretch over the wider bay 1, vault C has uneven vault halves. The uneven halves were made possible by the sexpartite division of the bay (meaning that the ribs dissect the width of the bay vault in addition to the two diagonal ribs), as the wider half only affects the vaulting above that bay's windows rather than the construction of the entire bay. Finally, the vault above the rounded sanctuary consists of half a rectangular vault (built as a normal rectangular vault) joined with an arched half-dome of sorts. The ribbing of the half-circle vault above the sanctuary indicates that five vault segments connect to form the rounded sanctuary vault. I built all five vault segments in the half-circle vault individually to ensure the vault segments were the proper size and in accordance with the floorplan. Having completed the vaults above the central aisle, only the walls containing the clerestory and oculus windows remained for me to model in order to to complete the interior of the choir.

The sizing and placement of the clerestory and oculus windows as they might have been in the late twelfth century is based on those put in place by Viollet-le-Duc in the nineteenth century. The oculus window is the round window that designates the third level of elevation and the clerestory window is the longer arched window that creates the fourth level of elevation. As discussed in Chapter Two, starting in the early thirteenth century (ca. 1225) the windows were replaced by large clerestory windows that took up the entire upper elevations rather than two separate windows. Viollet-le-Duc's reinstallation of the original oculus and clerestory windows were based on archaeological evidence and what was known of Gothic building trends from the 1160-1180, which can still be seen today in cathedrals such as Loan.[367] To build these windows in the model, I took measurements from an image of the windows I had scaled in Vectorworks to reflect the size of the bay. I then built the windows with simple geometry (a circle, and a square topped with an arch) to put the windows in place. The placement of the windows completed the third and fourth elevations of the cathedral model.

External Walls and Roof

The external walls and roof were the final addition to the model. Here, in the external walls I include not only the stone walls at the arcade and gallery level, but also the enclosing wooden wall at the west end of the choir, and external coverings of the vaults of the outer side aisle and the gallery. The outer side aisle and gallery vaults in the model are not covered with a roof, but rather with a thin horizontal object used to stop any sound leaks and fully enclose the structure. During this stage of modeling I

[367] Eugene-Emmanuel Viollet-le-Duc, "Entretien et restauration des Cathédrales de France. Notre Dame de Paris," *Revue générale de l'architecture et des travaux publiés* IX (1851). Bruzelius, in a footnote, argues that Viollet-le-Duc ``gives no indication as to whether they [the oculi windows] might have existed around the entire circumference of the choir." Bruzelius, "The Construction," 550. However, it seems unlikely that, when functioning as actual windows as opposed to decoration in the tribunes, they would have extended around the choir for uniformity of appearance. For more on window design and elevation in the late twelfth century see: Jean Bony, *French Gothic Architecture of the 12th and 13th Centuries* (Berkeley: University of California Press, 1983). Paul Frankl, *Gothic Architecture,* ed. Paul Crossley (New Haven: Yale University Press, 2000).

also created openings for and inserted windows into external walls of the gallery and arcade. In modeling the external walls, roof, and windows of the choir once again my main priority is to fully enclose the space and prevent leaks.

Compared to some of the other modeling work, constructing the external walls was a simpler task due to the simplicity of the shapes. I manually created walls from solid objects in order to make walls of the proper measurement. To build the external walls for the rectangular bays, I created a rectangle of 0.9m width that ran the length of the double aisle, then elevated the shape to be ten meters tall, creating a wall that enclosed the vault height of the arcade. I did the same for the opposite side of the choir. For the hemicycle, I created the external wall from arches that matched the curvature of the outer edge of the double aisle, forming a solid wall connecting to the walls already in place outside the rectangular bays. The measurements of the external walls of the arcade and gallery levels were based on measurements given by Hopin who lists the thickness of Notre-Dame's walls as 3 feet or 0.9 meters.[368] In the actual cathedral, the external walls are built in three layers: an exterior layer of limestone (visible from outside the cathedral), a gravel center filling, and the internal layer of limestone (visible inside the cathedral).[369] In my digital model, the walls are built as one solid object, omitting the change in materials. This omission was done for two reasons: first for ease of import into the acoustic software (the less detail the easier the integration), and second because the external wall acts primarily as a sound barrier and outer limits for

[368] Hopin, *How to Build a Cathedral*, 43. Hopin notes that the external walls of Notre-Dame are thinner than those of many other French cathedrals.

[369] Ibid., 43-44.

acoustic calculation making the change in material unnecessary for the model.[370] I followed the same procedure to model exterior walls of the gallery, as well.

Once the exterior walls were in place, I then had to put in the windows. The windows in the external walls are based on those depicted in Tallon and Sandron's laser scan, as there is little evidence about the previous external windows. Kraus, in *Gold is the Mortar*, includes an image of a window fragment he believes to have been donated to Notre-Dame in 1342.[371] However, he includes no measurements for the window.[372] The external windows in the digital model of Tallon and Sandron are a smaller duplication of the clerestory window shape of Notre-Dame cathedral: squared at the bottom with a pointed arch at the top.[373] This window shape is also consistent with the shape of the external windows seen in the cathedral today, but at a shorter length, so as to not take up the entire space of the wall. For the measurements, I chose to make the windows in the external walls proportionally similar to those in the clerestory in regards to the amount of space the window occupied in the wall. That is, the windows would take up the same amount of area on the walls in the bays of the arcade and gallery as

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370 I do acknowledge that with thinner walls elements such as weather and temperature could have more effect on Notre-Dame cathedral than they would have on the thicker walls of cathedrals like St. Denis or modern insulated walls and thus the sound waves within the cathedral. However, the present study will be unable to account for these variables. Discussion of the effects of temperature on sound and sound waves can be found in studies including: S. N. Sens, *Acoustic Waves and Oscillations* 3rd Edition (London: New Academic Science, 2014), 124-126. For information on wall Mass Law and design for sound isolation see F. Alton Everest and Ken C Pohlmann, *Master Handbook of Acoustics* Sixth Edition (New York: McGraw-Hill Education TAB, 2014), "The Mass Law and Wall Design."

371 Henry Kraus, *Gold was the Mortar: The Economics of Cathedral Building* (London: Routledge & Kegan Pual, 1979), 218.

372 Kraus, *Gold was the Mortar*, 23-24. Additionally, these windows would have been replaced or repurposed during the construction of the Chancellor chapels and the new styling of the exterior to reflect what is called the Rayonnant style. See: Bruzelius, "The Construction of Notre-Dame in Paris," 569. Mailan S. Doquang, "The Lateral Chapels of Notre-Dame in Context," *Gesta* 50, no. 2 (1002): 137-161. Bony, *French Gothic Architecture*, 357-41.

373 For the image see Tallon, *Notre-Dame: Neuf Siècles,* 23.

they do in the wall at the clerestory elevation. To model the windows, I created a solid object in the desired shape to make openings in the walls for the window and then to use the original object (and copies of it) as the windows. I used this same process to place windows in all the external walls and used the same measurements in the arcade and gallery, completing the exterior stone walls and windows.

The final historical architectural feature to be modeled was the wooden walls that enclosed the west end of the choir, as described in chapter two. These walls needed to fill all of the central aisle (from the ground up to the top of the central aisle vault 33m high), the gallery openings into the transept, and the double aisle on each side of the arcade. For each opening, I built a rectangular base and arch above to fill the area under arches and between the columns. I only had to build one such wall for each level (arcade, gallery) and was then able to copy and place the wall in place on the other side of the choir. I made each wall the same width to create a uniform thickness for the walls, thin enough to reflect the use of wood. With the west end of the choir enclosed, the model was then ready to be checked and modified for integration into the acoustic software.

To enclose any possible leaks from the vaults for the purposes of the acoustic testing, I covered the vaults with solids. These solids were not intended to imitate historical roofing or roofing techniques. They were intended only to fill the gaps between the external walls of the side aisle and gallery's, and of the gallery and walls containing the clerestory and oculus windows. For the arcade and gallery levels, I opted for the easy solution of creating a thin rectangular solid that connected to the base of the wall at the level above and extended to the width of the bays needing to be covered. For example, to cover the vaults of the arcade, I started the wall at the base of the gallery's external wall that was wide enough to cover the vaults of both side aisles and connect to the external wall of the arcade. I used the same modeling process to create the covering for the hemicycle vaults as I did to create the external walls. That is, I used the arch curvatures of the external wall of the hemicycle and external wall of the gallery to create a solid that filled the space in between the external walls above the hemicycle vaults. I did the same to cover the vaults in the gallery. To cover the vaults above the central aisle, I built a series of thin polygons that ran along the top of the exterior walls connecting to the vaults and meet flush above the center of the vaults. To cover the dome-like vault above the sanctuary, I created several triangular segments that followed the rounded edge of the walls below and that connected at a central point. After completing the roof above the central vaults, all of the vaults were then covered with a solid object to enclose the soundwaves.

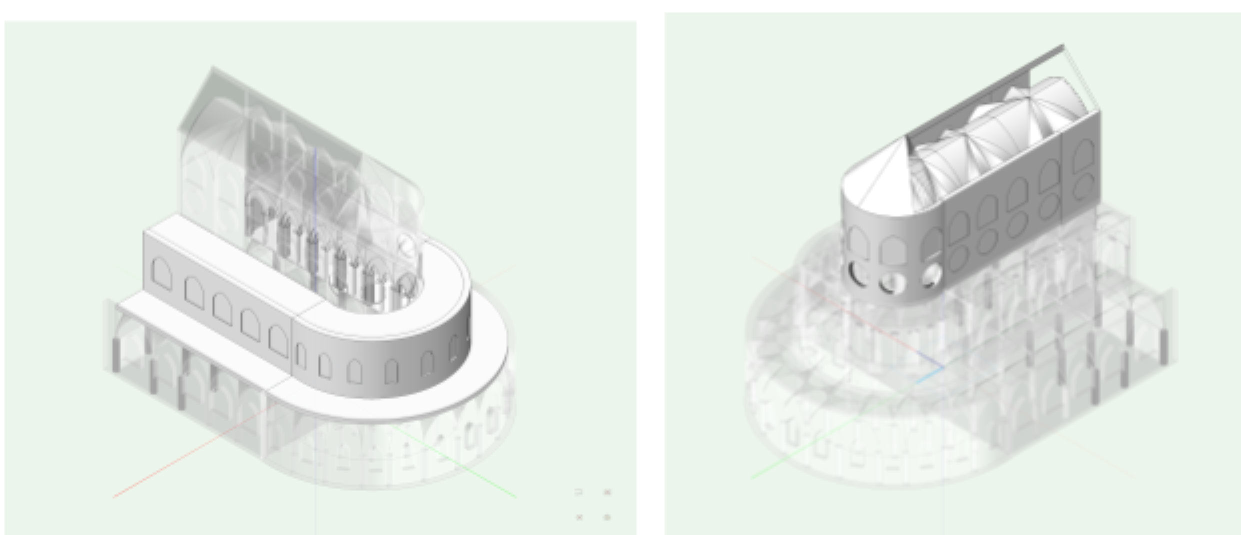

Figure 3.7 exterior coverings over vaults. Image Credit: Morgan, model of Notre-Dame built in Vectorworks 2019-2020. Seen left: the flat coverings over the gallery and floor level vaults. Seen right: view into the coverings over the central aisle vaults with the vaults below.

As described in the narrative above, the acoustic model I built is in no way a perfect model or a perfect recreation of the medieval space. Many important measurements were unavailable to me. Some of these measurements I had hoped to acquire while visiting the cathedral in Fall 2019, however, due to the 2019 fire, this was not possible. Additionally, in some moments my own modeling skills hindered the creation process. The modeling described above is the final version of the model, but does not include the many revisions, rebuilds, and remakes of many individual objects that went into building this model. Building the various vaults and wall facings throughout every level of elevation in the hemicycle in particular led to several overlapping or ill-fitting objects (particularly in the gallery walls facing the sanctuary). After beginning to work with an acoustic consultant to perform the acoustic testing, I would learn that the number of issues with my model were extensive, rendering my model unusable within the timeframe I had to complete the testing.

Acoustic Testing

The acoustic testing performed on my model of the choir took a different approach than originally planned. Initially, I intended to gain access to and learn to use an acoustic software package to personally conduct the testing. However, I was unable to bring that plan to fruition. Rather, to adapt and complete the research, I worked with Dawn Schwartz (MA in Architecture at the University of Florida) an outside consultant familiar with architectural softwares and EASE AFMG, an acoustic simulation software. The results presented below were produced by Schwartz. Schwartz worked with my original model to produce acoustic simulations in EASE AFMG. Before being able to run the simulations, however, Schwartz also had to modify and import the model of the choir into the program. Schwartz made a number of modifications of my original model to eliminate any overlapping surfaces and to close any gaps she could find. After importing my modified model into EASE, it was clear that my model still had far too many leaks to be usable for acoustic testing. I had failed in my aim to prevent leaks. In order to conduct the acoustic testing Schwartz built a new, simplified version of my model that still featured the correct measures, materials, and surfaces but reducing the amount of geometry and individual parts.

The placement and number of sound sources and sound receivers were based on information concerning the placement of singers within the choir and the varying polyphonic performance practices in the twelfth century. Schwartz produced six acoustic simulations: 1) four normal male voices (normal here, denoting a volume level, not register), 2) four raised male voices (raised again referring to the volume level), 3) two normal male voices, 4) two raised male voices, 5) one normal male voice, 6) one normal male voice. I chose to use four, two, and one sound source to imitate four-voice polyphony (with no doubled tenor), two-voice polyphony (also with no doubled tenor), and a soloist intoning the chant. The use of the normal and raised male voice was intended to estimate the volume of singing within the choir space, using the timbre provided by the software to simulate the reflections of the spoken and raised voices. Finally, the sound receivers were placed throughout the choir. However, the software calculated the acoustic values throughout the choir, evaluating over 100 different points. The software accounts for the entirety of the space in its calculations, producing images and graphics of the entire choir, rather than data only for the sound receivers. Having data for the entire choir means that we are able to see the different acoustic values throughout the choir to see the varying response times and values.

The Results

EASE AFMG has the capability of calculating multiple acoustic values relating to clarity and reverberation. Included here are the values for articulation loss, arrival time, clarity (c80), direct sound pressure level, echo, early decay time, t measures, total sound pressure level, speech transmission index, and modulation transfer index for three each simulation. To examine the results, I will first define each of the acoustic terms under discussion. Next, I will present the results in numeric values. Finally, I will interpret the results both in regards to acoustic industry standards (what acoustics deem good and bad values for different acoustic features) and discuss the impacts these results could have had on vocal music in the cathedral choir. I have manually compiled the measurements listed below and will additionally include the graphs showing the full range of results (those values over 1000Hz and values in between the measurements given here) in Appendix II.

In order to comprehend the results below, first the terminology must be defined. Listed and discussed below are the following acoustic qualities and measures:

- Articulation Loss: A measure of intelligibility of words by percentage of articulation loss of consonants.
- Arrival Time: A measurement of the arrival time of the direct sound from the sound source to sound receiver in terms of msec.
- Clarity (C80): A measure of intelligibility of music and individual sounds. C80 is “the ratio in dB of the energy in the first 80 milliseconds after the first sound arrival to the energy content arriving after the first 80 ms.”[374]

[374] *EASE 4.3 Tutorial*, 241.

- Decibel (dB): Unit of measurement of sound volume levels, one tenth of a bel. Unit "expressing the ratio between two physical quantities, usually amounts of acoustic or electric power, or for measuring the relative loudness of sounds."[375]
- Definition: measures what percent of the energy in the first 50ms after the first arrival is the initial sound versus the reverberation and reflections.[376] Closely related to clarity.
- Direct Sound Pressure Level (Direct SPL): A measurement of sound intensity and sound levels that does not include reflection or reverberation in the calculation. Measures sound levels from the sound source only.
- Echo Music: Measures the echo times (defined as delayed reflections that reach the sound receivers slower than .1 second after the initial sound) throughout the space.
- Early Decay Time (EDT): A measurement of "the time needed for the first 10 dB drop of the Schroeder decay curve and then extrapolates the 60 dB decay time by multiplying by 6. EDT figures are more related to the subjective RT (reverberation) impression a listener gets in a room."
- Hertz (Hz): Unit of measurement of frequency, measures number of cycles per second. Measures frequency/pitch of a tone.
- Sound Strength: "A dB ratio between the ratio between the total energy at the measuring location to the energy measured 10m from the same acoustic source in the free field."[377] Another measure of volume level.
- Speech Transmission Index (STI): A measure of intelligibility of words, STI "takes into account how the transmission from source to receiver is affected at different frequency bands and how much these frequency bands contribute to speech intelligibility."[378] STI is also specifically calculated for the male voice.
- T Measures (T10 and T30): A measurement of reverberation, T10 is the time required, after excluding the first 5 dB of decay, for the sound energy to decay another 10 dB. T30 is the time required for the sound energy to decay 30 dB.
- Total Sound Pressure Level (Total SPL): A measurement of the direct and reverberant/reflected sound energy in decibels (dB). Total SPL displays the total sound level. Total SPL correlates to the ear's perception of loudness.

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375 Encyclopaedia Britannica, 15th ed., s.v. "Decibel."

376 *EASE 4.3 Tutorial*, 238. See also: Leo Beranek, *Concert Halls and Opera Houses* (Cambridge: Springer, 1996), 24-26.

377 *EASE 4.3 Tutorial*, 243.

378 *EASE 4.3 Tutorial*, 239-240.

The measures for clarity (c80), definition, direct SPL, EDT, sound strength, T10, T30, and total SPL will be given in the tables below. Some of these measures, such as EDT, T10, and T30 had very minimal variation between simulations. I have opted to include the measure for each simulation regardless, so that the slight difference can be seen. In contrast, the arrival time, articulation loss, echo music, and STI measurements will only be given twice: first after the single voice measurements and again after the four voice measurements. The results for these four acoustic features (arrival time, articulation, echo music, and STI) are consistent in the results of the single and two voice simulations, with a slight change in the arrival time, articulation, and STI measures of the four voice simulations. Arrival time, articulation, echo music, and STI are only given in minimum, average, and maximum values due to how they are calculated and their results formatted in EASE. All acoustic qualities are listed in the appropriate measurement, as indicated in the left-most column of each table. [conclusion here?]

Let us begin with the acoustic measurements with a single sound source. For both the male normal voice and male raised voice, the amount of sound production for a single male voice is very low within the large space of the choir.

Table 3.3 Single normal voice acoustic measures

Feature (unit of measure)	125Hz	250Hz	625Hz	1000Hz
C80 (dB)	-4	-3.5	-3.5	-4
Definition (%)	22	23	24	21
Direct SPL (dB)	16.5	22.5	26	19.5
EDT (s)	3.6	3.85	3.7	3.75
Sound Strength (dB)	16.3	17	16.2	18

T10 (s)	3.5	3.9	3.8	3.85
T30 (s)	3.2	3.9	3.7	3.8
Total SPL (dB)	31.5	38	41	35

Table 3.4 Single raised voice acoustic measures

Feature (unit of measure)	125Hz	250Hz	625Hz	1000Hz
C80 (dB)	-3.1	-4	-3.5	-3.7
Definition (%)	24	20	21	20.5
Direct SPL (dB)	17	23	27	21
EDT (s)	3.1	3.8	3.7	3.75
Sound Strength (dB)	16.5	16.7	16.3	17.5
T10 (s)	3.2	3.8	3.85	3.85
T30 (s)	3.5	3.85	3.75	3.81
Total SPL (dB)	33	40	41.5	35

Table 3.5 Single voices additional measures

Feature (unit of measure)	Minimum	Maximum	Average
Arrival Time (ms)	3	23	11.7
Articulation Loss (%)	8.25	26.1	18.68
Echo Music (%)	0.53	0.82	0.60
STI (%)	.346	.559	.413

Unsurprisingly, the sound levels and sound output of a single voice is quite low. The direct SPL has a maximum of only 27 dB, equating roughly by modern standards to a quiet room or whispering; this means that the singer's voice dissipates quickly. The maximum of the total SPL reaches 41.5dB at 625Hz (a high countertenor range or the middle of the choir boy's range); while also quite soft, this indicates that a solo singer can in fact engender audible reverberation and reflections within the choir. However, a total sound level of 41.5dB—at a vocal range that likely wouldn't be reached by the average male singer at Notre-Dame—would still be softer in volume than a normal conversation. While audible, the soloist's voice is overwhelmed by the height of the vaults.

Most detrimental to the singer is the choir's poor clarity, articulation loss, and STI. The highest C80 value for a single voice in the choir is -3.1, which is quite low by modern acoustic standards.[379] Though it should be noted that the C80 values would affect soloist and small polyphonic ensembles performance more than that of choral singing (which would produce more sound, and thus have a different range of values).[380] The poor singing conditions were further impacted by significant articulation and speech transmission measures. The *EASE User Guide* classifies both the average articulation loss and STI measures as "Poor." The best values for both articulation loss (the minimum of 8.25) and STI (the maximum of .559) are categorized as only "Fair," leaving

[379] Beranek, *Concert Halls and Opera Houses*, 555-558. Though this discussion focuses on known C80 measurements of opera houses, the C80 values of the higher rated and preferred opera houses all have C80 values above 0.0.

[380] Choral acoustics continue to analyze the differences not only between choral and solo singing and sound production, but also on how the voices of large ensembles relate to one another, and how acoustic qualities affect soloists vs choirs. See: A.H. Marshall and J. Meyer, "The Directivity and Auditory Impression of Singers," *Acoustica* 58, no 3 (1985): 130-140. Sten Ternström, "Physical and Acoustic Factors that Interact With the Singer to Produce the Choral Sound," *Journal of Voice* 5, no 2 (1991): 128-143. Sten Ternström, "Long-time Average Spectrum Characteristics of Different Choirs in Different Rooms," *Voice* 2 (1993): 55-77. Sten Ternström, "Hearing Myself with Others - Sound Levels in Choral Performance Measured with Separation of the Own Voice from the Rest of the Choir," *Journal of Voice* 8, no 4 (1994): 293-302. T. Fischinger, K. Frieler, and J. Louhivuori, "Influence of virtual room acoustics on choral singing," *Psychomusicology: Music, Mind, and Brain* 25, no 3 (2015): 208-218.

much to be desired in regards to articulation loss and speech perceptibility. Words of the liturgy were likely hard to perceive from the opposite side of the choir - a detriment to readings and responsorial practices. As will be discussed below and in the next chapter, poor word comprehension will impact some polyphonic genres more than others.

Table 3.6 Two normal voices acoustic measures

Feature (unit of measure)	125Hz	250Hz	625Hz	1000Hz
C80 (dB)	-2.5	-3	-3	-3.5
Definition (%)	24	23	23.5	23.4
Direct SPL (dB)	19.5	26	29	23
EDT (s)	3.2	3.9	3.7	3.8
Sound Strength (dB)	16.6	16.9	16.5	18
T10 (s)	3.5	3.8	3.7	3.8
T30 (s)	3.5	3.9	3.7	3.8
Total SPL (dB)	36	40	44	38

Table 3.7 Two raised voices acoustic measures

Feature (unit of measure)	125Hz	250Hz	625Hz	1000Hz
C80 (dB)	-3.5	-4	-2.5	-4.1
Definition (%)	21	22	28	20
Direct SPL (dB)	19.5	25	29	23
EDT (s)	3.2	3.9	3.7	3.75
Sound Strength (dB)	16.6	16.8	16.4	17.5

T10 (s)	3.5	3.9	3.7	3.8
T30 (s)	3.5	3.8	3.75	3.8
Total SPL (dB)	36.5	40	44	38

Two singers fare little better within the choir than does a soloist. As seen above, while the two singers do produce more sound overall, the improvement in values such as direct SPL, total SPL, and clarity—particularly at 250Hz—is slim. However, for the lower male voice range at 125Hz there is a notable improvement in total and direct SPL. For the *organa* settings that use bass tones or low tenor ranges in the tenor voice (and especially on those occasions that the tenor voice is doubled) the use of two voices had a minimal advantage in sound production over the single voice. The limited increase of sound production between one and two voices can readily be seen in the sound strength measures—the values are roughly equivalent. However, singers of two voice *organa* settings face additional challenges that the soloists would have faced.

The clarity measures (that is, when comparing the normal and raised measures between the single and two voices) are also improved by the use of two voices instead of one, but the results are still outside the desired range for acousticians today. In fact, the definition measures for the two normal male voices are only minimally better than the definition measures with a soloist, but still quite poor. According to the EASE user guide, acousticians consider a definition of greater than 50% to be desirable, as this means that the majority of the sound heard by the listener is from the sound source rather than the reverberation or reflections. Poor clarity and definition would have impacted singers of *organa duplum* more so than the soloists. With poor clarity it becomes harder to aurally distinguish between the different voice parts (an issue that already would have been made difficult by the tenor and duplum voices singing in the same range), their harmonies, and, with high articulation loss, to distinguish the words in faster moving sections. Additionally, the fast moving notes would have been difficult to distinguish within the choir. The un-ideal clarity and definition coupled with the low sound levels would also muddy the sound of intricate melismas for listeners if the singer is moving through them quickly.

Finally, here are the results with four sound sources. While the increase of values between one and two voices was limited, there are some noticeable differences between two and four voices.

Table 3.8 Four normal voices acoustic measures

Feature (unit of measure)	125Hz	250Hz	625Hz	1000Hz
C80 (dB)	-2.4	-2.5	-2.4	-2.5
Definition (%)	23	22	22	21
Direct SPL (dB)	23.5	30	33	25
EDT (s)	3.1	3.9	3.6	3.8
Sound Strength (dB)	16.6	16.7	16.5	18
T10 (s)	3.4	3.9	3.75	3.8
T30 (s)	3.2	3.9	3.75	3.85
Total SPL (dB)	38	43	45	41.7

Table 3.9 Four raised voices acoustic measures

Feature (unit of measure)	125Hz	250Hz	625Hz	1000Hz
C80 (dB)	-2	-2.3	-2.3	-2.4

Definition (%)	23	24	26	23
Direct SPL (dB)	23	30?	33	26
EDT (s)	3.0	3.8	3.6	3.8
Sound Strength (dB)	16.9	17.2	16.7	18
T10 (s)	3.4	3.9	3.7	3.7
T30 (s)	33	3.9	3.75	3.8
Total SPL (dB)	39	46	47.5	41

Table 3.10 Four voices additional measures

Feature (unit of measure)	Minimum	Maximum	Average
Arrival Times (ms)	2	19	9.73
Articulation Loss (%)	9.41	25.45	18.45
Echo Music (%)	.5	.7	
STI (%)	.351	.535	.415

With four voices there are many noticable changes in the measures in comparison to the effects of two voices, as a result of the increase of sound production. With four voices singing, the average arrival time decreases, and direct and total SPL increase to reflect the doubling of voices. Despite doubling the amount of sound, however, the SPL values increase only minimally —4dB at most—indicating that even four polyphonic singers would have struggled to fill the choir and the vaults with sound. Even for the four male voices, the highest SPL values are still found at 625Hz, with the measures at 250Hz only 1.5-3dB lower. Though interestingly, while the SPL values increase over those for two voices, the sound strength measures with four voices does not. The lack of a higher sound strength measure further emphasizes the amount of sound needed to truly fill the choir with sound.

While the sound levels do increase, the issues of clarity and textual comprehension remain. Clarity values improve marginally, evening out to a range of -2 to -2.5—the best clarity values out of the three simulations and the most stable between the four frequencies. The sound definition, however, doesn't improve with the values remaining in the same range as the other simulations. Interestingly, the increase of sound production benefits the overall clarity but doesn't change proportionally the amount of sound perceived through reflection and reverb as can be seen in the definition measurement. Additionally, the articulation loss and STI worsen, if only by minor decreases. The average of both are roughly the same between four voices and one voice, but the minimum is higher by just over 1%—likely not a perceivable improvement. Having four singers might increase clarity and articulation loss, but they would still have been impeded by these values.

When considering all the results together, there are several things worth noting. First, note that the reverberation time of only the choir area was far different from the wet reverberation times of the full cathedral seen above. In fact, the drier 3.8 second reverberation time could have suited all textures of polyphony being performed in the choir if not for the overall poor clarity. Second, the low clarity of the choir space, coupled with a poor STI and high articulation loss, is shown to have been ill suited for the melismatic textures of *organum duplum* and the fast moving words of *conducti*, but could have been advantageous for the *quadrupla* and emerging discant settings. Third, the SPL values and reverberation times have their highest values within the 250-625Hz level— the frequency range that encompasses the vocal range of any tenor singers and choir boys, or the voice types who were the majority of the chapter's most frequent singers.[381] Fourth, given the vocal ranges that would have been present in the choir, the sound strength levels are highest at 125 and 250Hz. This means that the baritone and lower tenor singers had a slight sonic advantage within the choir. Fifth, the above results further indicate that group chanting was perhaps the only type of singing that could have filled the new choir with sound. With thirty or more singers, the sound output would have been significantly higher than that of four voices. Overall, the polyphonic singers faced many sonic challenges within the choir of Notre-Dame.

The low sound pressure levels in all three simulations suggests that the height of the vaults was difficult to fill with sound. The highest decibel level is from the four raised voices simulation, but at only 47.5dB—almost a level comparable to an "urban residence" or barely louder than "moderate snoring"—it would have been an almost negligible level of sound for such a large performance space. The solo singers in particular would have struggled with sound production, with sound pressure levels reaching a maximum of only 41dB ("soft whisper" or "quiet urban residence") and drops to 31.5dB ("recording studio" or "library" quiet) at the lowest. The results indicate that the height of the vaults requires a large amount of sound to fill, and that the size of the choir overwhelmed the singers. As will be discussed in the next chapter, the low sound levels in the choir would have required many adjustments to be made to combat construction noises and the greater loss of sound when the choir was joined with the

[381] See "polyphonic singers" in the introduction chapter. A significant number of tenor singers at Notre-Dame cathedral is indicated by the ranges of melodies and clef placement within the manuscripts, however a more significant study of the correlation between melodic range and personnel is still in need.

transept and the nave, and when the walls of the choir were removed to make way for new windows.

Conclusions

The process of answering the question “what did the choir space alone sound like” produced many processed based inquiries in addition to the acoustic test results. In particular the process of building the digital model raised many questions about the measurements of the cathedral’s architectural elements. Additionally, the modeling process called into question the advantages and limitations of digital technology and methods. The digital methods demonstrated in this chapter enabled me to simulate and approximate the acoustic values of a performance space now lost to history. However, digital methods also highlight the challenges facing the modern researcher, such as access to softwares and training, resources, and having to create each stage of analysis from scratch. Despite the challenges, the acoustic results did reveal vital information about the medieval choir as a performance space.

Digitally modeling a previous iteration of Notre-Dame cathedral raised many questions and challenged my perception of the space. Building the model emphasized what is known and unknown about the medieval choir. The process further highlighted the limitations of current knowledge of the cathedral. While there are many well-known or well discussed measurements such as the height, width, and length (and even those measures vary, particularly the height) many of the smaller measurements, such as the width of the arch profiles, go unmentioned or undisclosed. Tallon and Sandron’s laser scan would have produced data for each aspect of the cathedral from height to the width and contours of every arch profile and every wall. However, just like access to the cathedral itself, those measurements are inaccessible. As discussed above, my experience building the model of the choir would have been more exact (and easier to some extent) had I been able to confirm and take measurements of the architectural features around the cathedral. In a future iteration of this project, I would ideally be able to conduct measurements in the cathedral itself of each feature.

Additionally, I would like to begin the modelling process again to incorporate some modeling techniques and options I hadn't thought of or even considered in the model discussed above. Since revising the model to send for import into the acoustic software, I have developed new methods for modeling objects in the hemicycle in particular. Rebuilding the model (post-confirmation of measurements, ideally) would allow for renewed acoustic testing with a more detailed version of the choir. A more detailed version of the acoustic model had been intended as part of the acoustic results above, but we were unable to bring it to fruition within the limited time frame available. Though, it should be noted that the results of the acoustic testing would have been only minimally altered. Finally, I would use the opportunity to expand my model to include later phases of construction to gather acoustic measures of multiple stages of the incomplete cathedral. Expanding the acoustic tests would provide data on the extent to which missing walls and the addition of the transept and nave changed the acoustics of the space and thus how sound production and musical practices would have been impacted at every stage of construction. Furthering the acoustic tests would also enable an exploration of the degree of error in the acoustic testing to deepen the understanding of the acoustic model and simulation results.

The above acoustic testing has revealed the sonic conditions faced by the polyphonic and solo performers of the late-twelfth and early thirteenth centuries. The acoustic measurements indicate issues with clarity, articulation loss, and low sound level resulting primarily from the unprecedented height of the central vaults. The limited changes in the acoustic measures between one, two, and four voices further suggests that soloists and polyphonic singers alike would have needed to make vocal adjustments in their new performance space. Performance of each texture of music—from chant to *conducti*—faced acoustic and thus sonic challenges.

In conclusion, what did the choir space alone sound like? The medieval choir was reverberant, but far less reverberant than the complete cathedral would be. A large amount of sound production was required to fill the space and balance the direct and reflected sound. The medieval choir had a slight echo due to the late reflections from the overhead vaults. It had high articulation loss, making genres like the *conductus* and at least solo chanting difficult for listeners to comprehend. Each texture of polyphony would have been impacted differently and required different performance adjustments from doubling voice parts to using new rhythmic textures. The singers within the choir would have needed every technique at their disposal to adjust their singing to counter the poor acoustic qualities and to take advantage of those qualities that benefit their performances. It is to the sonic experience of the singers and listeners in the choir to which I now turn.

Sounding Space: Listening and Polyphony within the Choir

Between 1182 and 1208 the chapter members of Notre-Dame worshipped and performed the liturgy within the newly constructed choir of the cathedral. The choir was enclosed with wooden walls to separate the sanctuary from ongoing construction that continued through the thirteenth and into the fourteenth century.[382] Members of the chapter and singers had to adapt to their new acoustic space and the challenges that came with performing and worshipping within a construction site. Not only did they have to contend with construction noise throughout the years of window renovations and the addition of the chantry chapels that began in the mid-thirteenth century, but they also had to contend with missing walls throughout the choir. During this period, the choir and its acoustics played a pivotal role in the development of Notre-Dame polyphony, particularly at the end of the twelfth century. The acoustics of the new choir would have impacted musical practices of every hour of the Office and every Mass, as well as the singing of every type of polyphony.

During their time in the enclosed choir, the singers of Notre-Dame would have taken steps to adapt to the acoustics of their new choir. As examined in the previous chapter, singers faced many sonic challenges in their choir space. The high vaults created long reverberation time averaging 3.8 seconds, and required a large volume of sound to fill the space. The long reverberation times and high ceiling height produced an overall low sound pressure level (a low volume) even for four-voice ensembles. Additionally, poor clarity (C80) and definition values not only obscured the voice parts

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[382]See the cathedral's construction history presented in Chapter Two.

for listeners, but also could muddy the intricate melodies. Further, high articulation loss distorted spoken readings and text-filled music genres including chant and conductus. The extent to which comprehension and overall aural feedback was impacted, however, depended on the type of performance. Variables including number and position of the singers and the type of polyphony would have affected the aural feedback of polyphonic performance within the space of the choir. Given what is known about the acoustic environment, what could each type of polyphony have sounded like?

In this chapter I explore the aural feedback of singers and listeners, and the sonic implications of *organum duplum, triplum,* and *quadruplum* and discant within the choir of Notre-Dame. In order to do so, I combine methods from sound studies, acoustics, and music analysis. By music analysis I do not mean score analysis, but rather, the examination and consideration of how different rhythmic, melodic, and harmonic features of the different types of polyphony would have interacted with the acoustics of the choir. I combine knowledge of the choir space and its materials, the performance practices of the chapter, and the acoustic results of the previous chapter of this dissertation to explore a holistic understanding of musical sounds within Notre-Dame's choir as it might have stood in the late twelfth century. I preface my analysis of singing and listening within the choir with a discussion of medieval knowledge of sound and acoustics. Whereas medieval acoustic knowledge was far from what we know today, multiple sources point to an awareness of sound within worship spaces. Next, I examine the impact of the sonic characteristics within the choir, such as echo, dynamics, and overtones, on singing and listening experience. I then explore the aural feedback experienced by listeners in locations throughout the choir with reference to the acoustic features that most impacted their listening experience. Finally, I explore the advantages and limitations of singing each polyphonic texture (*organum duplum, triplum, quadruplum* and discant) and how each texture could be modified or adjusted to address acoustic difficulties.

The following discussions are once again based on a number of assumptions. First, as discussed in Chapters 1 and 2, a central part of my analysis is that polyphony was improvised. Second, is the assumption that four-voice settings were not necessarily new when Odo of Sully wrote his edict in 1198.[383] Sully's edict has been used to date Pérotin's *quadruplum* settings, but the language therein does not indicate that any of the textures (two, three, or four-voice organum) were new at that time. Rather, in grouping two, three, and four-voice polyphony together Odo implies an interchangeability, familiarity, and/or comfort with all three practices occurring at the cathedral. The final assumption is that, although the chapter's liturgical practices were in place before the construction of the cathedral, some flexibility and adaptation must have been made early during the construction process. Some of the proposed adjustments would have been made for musical or aesthetic purposes. Most, however, would have been made for practicality and facilitation of the liturgical practices. The acoustic results suggest several changes in performance practice would have been necessary, or, at the very least, would have improved the listening experience for the most important members of the chapter. I propose possible adjustments of varying types, some of which would have been bigger changes than others (e.g., moving singers a couple feet closer to the altar

[383] Craig Wright, *Music and Ceremony at Notre Dame of Paris, 500-1500* (Cambridge: Cambridge University Press, 1988), 238-239.

in the choir versus adding a second soloist to intone the chant), so it is necessary to explore the full range of options available to the singers of the late twelfth century.

Medieval Acoustic Knowledge

Medieval writers, intellectuals, and singers demonstrated knowledge of sound and acoustics in multiple ways. First, in the early twelfth century a translation of Aristotle's *De anima* was made and circulated in Western Europe in a variety of formats, providing a basic knowledge of acoustics and sound. Second, in their writings, medieval writers ruminated on and debated how sound was produced, the mediums through which it could travel and how it was perceived.[384] Third, chapter members of medieval churches and cathedrals added and installed materials such as wall hangings, carpets, and *jubés* (stone or wooden structures surrounding the sanctuary and choir to separate the worship space from the congregation) within the cathedral or church space. The added fabrics served both aesthetic and acoustic functions. Given these types of acoustic modifications, medieval singers and church personnel must have had an understanding of sound in their environment and how to create a desired listening outcome.

Medieval texts indicate that intellectuals had a basic knowledge of how sound traveled. Aristotle's *De anime*, which was translated into Latin in the late twelfth century (circa the 1150s) provided knowledge of how sound was produced and transmitted.[385] Even before that translation, Aristotle's teachings on sound production circulated in

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[384] Charles Burnett, "Sound and its Perception in the Middle Ages," in *The Second Sense: Studies in Hearing and Musical Judgement From Antiquity to the Seventeenth Century*, eds. Charles Burnett, Michael Fend, and Penelope Gouk (London: The Warburg Institute, 1991).

[385] Ibid., 43-70.

re-interpretations by Avicenna (Ibn Sīnā, c.980-1037, translated to Latin by Dominus Gundissalinus in the 1160s), Averroes (Ibn Rushd, 1126-98, not translated until the early thirteenth century by Michael Scot), and similar teachings were described in Boethius' *De institutione musica,* a text read widely in the Latin West.[386] Aristotle described how sound is produced by striking two bodies together (such as a bronze hollow object), the voice, or strings (instruments that have pitch, melody, and articulation), and how the sound then travels by moving the air.[387] Based upon the translations of Aristotle, Avicenna, and Boethius, twelfth and thirteenth-century intellects continued the debate of how sound was produced and perceived.[388] In particular, Adelard of Bath (c.1080-c.1152), Robert Grosseteste (c. 1170-1253), Albertus Magnus (1207-80), Thomas Aquinas (1225-74), and Jacques de Liège (c. 1260-1330) debated how different instruments, and especially how voices and strings produced sound, through what mediums sound could travel, and how the ear and brain was able to perceive and process sound.[389] Writings such as those by Avicenna, Magnus, and de Liège demonstrate an investment in acoustic knowledge through the Latin West during the medieval period.

Medieval and Renaissance knowledge of acoustics also was demonstrated through the addition of acoustic technologies and the placement of musical practices and listeners within. In medieval Byzantine churches, wall paintings of figures singing or

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[386] Ibid., 44. Avicenna, *Avicenna Latinus. Liber de anima*, 2 vols, ed. S. Van Riet (Leidon, 1968-72).

[387] Ibid., 47 & 52-54. See also: Aristotle, *De Anima. Books II and III*, trans. By D. W. Hamlyn (Oxford, 1968), 419b16 &420b5-10.

[388] Ibid., 44.

[389] Ibid., 43-70. Albertus Magnus, "De anima," in *Opera omnia*, ed. C. Stroick (Munster, 1968). Thomas Aquinas, *In Aristotelis librum De anima Commentarium*, ed. A. M. Pirotta (Turin, 1925). Jacques de Liège, *Speculum musicae*, ed. R. Bragard (Corpus scriptorum de musica 3: Rome, 1955).

of music were placed in locations that had strong aural feedback, indicating that the personnel at the churches were aware of a building's particular acoustics and listening experience.[390] Similarly, in Renaissance Venice following the renovation of St. Marks and the addition of a new choir screen, the Doge's chair was moved to ensure the best possible listening experience possible.[391] Cathedrals throughout France, such as those of Noyon and Lyon, also began to add acoustic pots to their cathedrals the function of which was explained by the architectural teaching of Marcus Vitruvius (ca. 81-15 BC), who explained the function of acoustic pots.[392] These examples demonstrate that singers and listeners were aware of their acoustic environment, and that adjustments were made to improve the listening experiences for important members of the congregation. Further, they indicate that church personnel and singers were making adjustments and striving for improvements in their sound.

The chapter of Notre-Dame added acoustical modifications to the cathedral including wall hangings, carpets, and a *jubé*. Wall hangings, silks, and carpets were used in Paris' churches even before the construction of the new cathedral, a practice that continued through construction and beyond. For further acoustic alteration, and for liturgical and aesthetic reasons, in 1351 a tall, stone choir screen was built around the edge of the sanctuary and later replaced with a wooden *jubé* around the central aisle of

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[390] Spyridon Antonopoulous, Sharon Gerstel, Chris Kyriakakis, Konstantinos Raptis, and James Donahue, "Soundscapes of Byzantium," *A Journal of Medieval Studies* Vol 92, No S1 (October 2017): S3221-S335.

[391] Deborah Howard and Laura Moretti, *Sound and Space in Renaissance Venice: Architecture, Music, Acoustics*, (New Haven: Yale University Press, 2009), 17-42.

[392] Marcus Vitruvius, *De architectura libri decem (Ten Books on Architecture)*, ed. Ingrid D. Rowland and Thomas Noble Howe, trans. Ingrid D. Rowland (Stuttgart: Steiner Verlag Wiesbaden, 1986). On Noyon Acoustic Pots see: Andrew Tallon, "Acoustics at the Intersection of architecture and Music: The *Caveau Phonocamptique* of Noyon Cathedral," *Journal of the Society of Architectural Historians* 75, no.3 (Sptember 2016): 263-280.

the cathedral's choir in the 1400s.[393] Enclosing the central aisle, the *jubé* not only separated the chapter from the congregation but created a more isolated performance space—perhaps one intended to improve sound quality.[394] Indeed, the stone choir screen in particular may have served to mitigate many of the acoustic issues by fully enclosing the choir space to better contain sound and to strengthen lateral reflections to the chapter.[395] The choir screen could then be further covered with clothes and tapestries to deaden some of the reverberation and reflections. It is documented that the chapter added more wall hangings and other fabrics throughout the cathedral in the fourteenth through the fifteenth centuries, likely in an attempt to dampen the cathedral's reverberations when more melismatic polyphony became the prominent practice at the cathedral.[396] Because of the noted intense reverberations within the choir and (later) within the complete cathedral, the singers of Notre-Dame would have needed more than just fabrics to shape and adapt their musical practices to the acoustic environment.

Sonic Effects and Implications

As an aural environment, the choir's acoustics produced a number of sonic effects, primarily as products of long reverberation times and late vertical or overhead

[393] Michael T Davis, "Splendor and Peril: The Cathedral of Paris, 1290-1350,"*The Art Bulletin* 80 no. 1 (march, 1998): 46-47. Wright, *Music and Ceremony*, 9 & 339. For more on the history of Gothic Choir Screens and Notre-Dame choir screen in particular see Jacqueline E. Jung, *The Gothic Screen: Space, Sculpture, and Community in the Cathedrals of France and Germany ca 1200-1400* (Cambridge: Cambridge University Press, 2013), 16-41.

[394] The quick shift from stone to wood may also be suggestive of a consideration towards sound. Wood would absorb more vibration and reflections than the previous stone walls, thus doing more to dampen the reverberation particularly in combination with the wall hangings.

[395] The acoustic effects of the choir screen is an area that deserves more exploration than is present here and will indeed be part of future acoustic modeling and simulation.

[396] Wright, *Music and Ceremony*, 18.

reflections. Acoustic features such as echo or overtones could have been incorporated into musical practices, but any failure to do so would have been a great detriment to musical practices at the cathedral. The vaults stretching up above the heads of the chapter, played a significant part in the acoustics and aural feedback to both the chapter's singers and listeners. A lot of sound was lost in the height of the vaults, reducing the volume levels withins the choir and drastically altering the balance of direct and reflected sounds. Additionally, sound reflection down from the vaults to the chapter members below produced an echo that conflicted with the faster lateral reflections at floor level within the choir. Every acoustic quality would have been affected by the height of the vaults, impacting all musical practices in the choir.

Reflections at ground level could have been reduced and controlled by the chapter members by addition of wall hangings and carpets. For feast occasions, especially annual feasts such as Christmas, the chapter would have hung many silks, draperies, or tapestries around the choir and added carpets to the choir floor. Such hangings would absorb some of the soundwaves reflected from the stone walls of the choir and hangings on the wooden wall would help to dampen external noise and help to insulate the choir from sonic disturbance. If the addition of wall hangings and carpets reduced reverberation time by even 0.5 seconds, it would have been enough to decrease the reverb to less than (or close to) 3 seconds for frequencies at and below 625 Hz.[397] Shortening the reverb times would have produced further effects, including reduction of some of the late reflections and echo present in the choir. However, while reducing some of the lateral reverberation and echo, the addition of fabrics would likely have made the overhead resonance and reflections even more prominent. The

[397] For non-dampened reverb times, see Chapter 3 "The Results."

reduction of lateral reverberation would not eliminate any of the negative acoustic features, but with enough sound absorbing materials, a more intimate and less reverberant listening space could have been created.

The acoustic conditions within the choir made sound production susceptible to interference, particularly from loud noises associated with construction. Even in a quiet choir, singers would have struggled to project one- and two-voice polyphony within the space - but the sharp noises of hammers on stone would have greatly disrupted singing and even some services.[398] Therefore, as discussed in Chapter Two, it was likely that construction halted for Mass daily, and possibly, either for the entire day or for the hours of the Office during important feasts (perhaps feasts of nine-lessons or higher—those same feasts that received polyphony). Because of low overall sound levels, soloists and two-voice ensembles would only have been heard well in ideal listening conditions: those without external or loud internal noises. The melismatic upper voice of organum and soloist intoning the chant in particular would be overwhelmed by noise and the removal of walls.

Singers and listeners alike would have needed to adjust to the wildly different sound levels between chanting and polyphonic or solo singing. Throughout the evening Mass in particular, singing regularly would have been exchanged between a soloist, polyphonic singers, and the group chanting of the chapter as necessitated by the responsorial singing practices of Gregorian chant. Sonically, the contrast between one to six singers or soloists and the force of the full chapter singing would have been immense. For the soloists and polyphonic singers especially, moving from the

[398] See Chapter Two for the discussion of the daily hours and when construction could have been halted to eliminate noise pollution.

comparative whisper-quiet of a solo singer, or the conversation-level quiet of four voices to the comparative thunder of over fifty chanters could have been jarring, not only for the difference of volume but also the reverberant aftermath. To be heard by the chapter, soloists and polyphonic singers would have needed to wait for the sound to fade before beginning the next chant or verse. The chapter could join for singing in time, provided that they joined with the singers and not with the echo.

Echo within the choir, produced by the height of the vaults and long reverberation time, would constantly have affected performance and listening. Seen in figures 4.1 and 4.2, different listening locations experienced the echo at slightly earlier or later times. The echo times four four voices (seen in fig. 4.1) are shorter on average than the measures for a solo singer (fig. 4.2). With four singers, the majority of the listeners under the central aisle would have experienced an echo delay of 0.6-0.65 seconds whereas the singers (standing at the altar steps) would have experienced a 0.7 second echo time. In contrast, echo times under the center aisle with a solo singer increases to a more varied 0.6-0.75 seconds (fig 4.2), with the majority of listeners experiencing the longer 0.7 second echo. Echo times also changed depending on the number of singers, adding more auditory confusion. The echo would have reduced the comprehension of words, added harmonies to the setting, and impacted the unity of singing in each type of music at the cathedral. A sounding echo likely produced the effect akin to having another ensemble singing out of sync, that texturally may have been equally interesting and distracting.

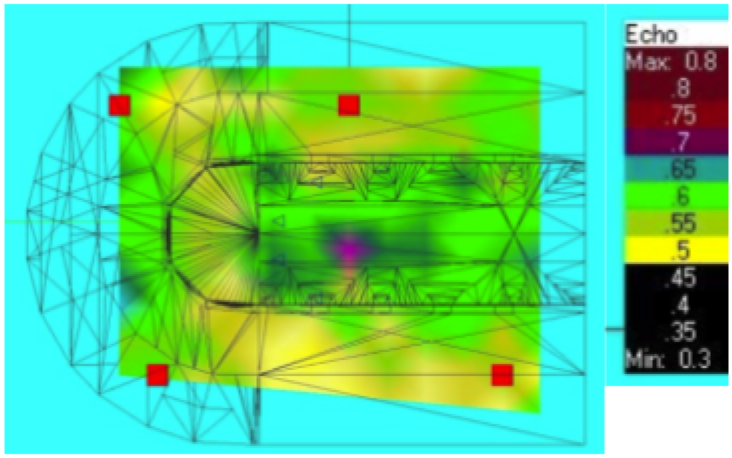


Figure 4.1 Echo music visualization, four raised male voices. Image Credit: Schwartz 2020 acoustic simulation, *EASE AFMG* 4.4.

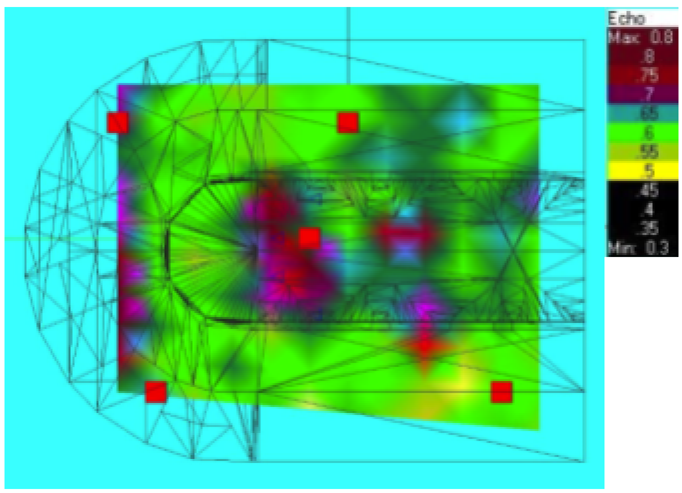


Figure 4.2 Echo music visualization, single normal male voice. Image Credit: Schwartz 2020 acoustic simulation, *EASE AFMG* 4.4.

Sonically, the noted echo produced complications for monophony and polyphony. First, the late reflections of the echo caused all music in the choir to have apparent added harmony. The monophony of chant and the florid solo lines of *organum duplum* would have added unintentional harmonies while *quadruplum* and discant settings would add additional harmonies that thickened the texture. Singers could have made musical adjustments to diminish or work with the impact of the echo, including using more repeated pitches and slower or faster tempos, but the only way to prevent the echo from impacting each tone would be to pause between every tone or syllable—an impractical solution. Techniques to accommodate the echo within the performance would have depended on the texture of polyphony. Singers of *organum duplum* likely would have struggled with the echo, particularly alongside issues of low sound production and clarity. The organal voice in particular would have needed to adjust its melody so that the echo's harmonies did not produce jarring harmonies like the tritone. Tempo would also play a role in affecting which notes harmonized with the echo. In all musical textures—from duplum to quadruplum—tempo and melody dictated the tones that sounded against each other. Increasing the repetition of tones or intervals would be one easy way to produce consonant harmony with the echo of the choir.

The choir's long reverberation times and late reflections made the choir space an active, sounding part in all musical practices. Rather than direct sound, overheard reverberation and late reflections would have been the last sounds of the chant or polyphonic setting heard by the chapter. Within the vaults, multiple voices would resound simultaneously as new tones entered and previous tones reflected into and out of the vaults. The vaults of the choir reflected the singers' voices back to them and to the rest of the chapter with some delay depending on who was singing and how many voices were sounding.[399] At the end of a verse or setting, listeners and singers alike would hear the extension of their final phrases, maybe with overtones. Reflections from the vaults would last seconds after the singers ended their final tone, almost as if the vaults were singing back to the singers.

As an additional complication, the prominent reverberation in the choir could also produce overtones made more distinct if the singers were singing well in tune. The overtone series is a sequence of sympathetic frequencies derived from the fundamental

[399] The delay consists of both the 0.3 second or more echo as well as the 3 or more second T30 times.

frequencies produced by the singer or musician. For instance, if an organist plays a C2 (low in the bass range), the overtones produced will include tones an octave above the fundamental frequency, a fifth above the sympathetic octave, a fourth above the sympathetic fifth, and more intervals above the fourth as can be seen in figure 4.3.

Figure 4.3 First sixteen tones in the overtone series from fundamental C (labeled 1).

The open fifths and octaves produced in all polyphonic settings, especially if repeated and sustained, could have produced multiple overtones including the sympathetic third (actually tenth, up an octave from the fundamental tone), as well as the octave tone above the highest voice.[400] With sounding overtones, tones of at least three octaves could sound simultaneously—the lower octave of the tenor, middle octave of the upper voice(s), and the overtone octave(s) above. Further overtones could also be produced by the harmonic intervals sung throughout polyphonic settings. For instance, singing a well-tuned perfect fifth could produce the sympathetic third, adding a harmony to the frequently sung open fifths and octaves. Pauses in between verses and at the ends of settings would have given listeners the opportunity to hear the overtones unobstructed when produced. Overtones could also ring throughout each setting, accompanying the singers and the echo, deepening the harmonic texture.

[400] Support for hearing overtones coming in particular from Gerstel and Kyriakakis' work on Thessaloniki. Kyriakakis was able to isolate the reflections in vaults from their acoustic testing at Thessaloniki. Audible in those sound bites were the overtones produced within the dome sounding over an octave above the singer's voice. Sharon E. J. Gerstel and Chris Kyriakakis, "Sensing Sacred Acoustics." paper presented at Sound and the Sacred, University of California Los Angeles, CA, November 2017.

The sonic effects of the vaults—from the echo to the overtones—could have both challenged and aided musical performance and practices within the choir space. Aural feedback from the echo and overtones would have provided the effect of additional sounding voices and created an expected wash of sound that could be incorporated into musical practices. As will be discussed below, however, the echo and reverberant overhead vaults would pose many problems for the more melismatic polyphonic settings. Additionally, the striking shift between the volume levels of solo singing, polyphonic singing, and group chanting would have made signers very aware of the vaults overhead, as well as the sonic challenges they faced in performance. The acoustic features and aural feedback from the vaults were factors that had to be considered most carefully during performance.

Aural Feedback: Listeners throughout the Choir

The listening experience within the choir may have initially been an awkward one. Sitting in long rows along the length of the choir, listeners' experiences would have depended on where they sat and the distance to the singer(s). The shape of the central aisle, narrow and long with a high vaulted ceiling, resulted in fast lateral reflections but long overhead reverberation.[401] Additionally, the change in vault shape from east to west, the rounded vaults above the sanctuary to the east but rectangular vaults to the west, changed how sound reflected back down to the chapter. Most importantly, the height of the vaults meant that much of the singers' sound rose above the chapter, lowering the overall sound levels to sometimes whisper soft levels, whereas

[401] Under the central vault arrival times were as short as 19 milliseconds with an ITDG (Initial Time Delay Gap) was between 0-1.5 milliseconds depending on location. The fast ITDG times undoubtedly correlate to lateral reflections rather than ceiling reflections.

reverberation reflected down to produce echoes within the choir space. The acoustic effects—how the reflections from the overhead vaults reached the chapter and altered the balance between direct and reflected sounds—would have been perceived differently at various positions in the space.

Members of the chapter had assigned seats in the choir during mass. As discussed in Chapter Two, the chapter members were seated among the choir stalls based on their administrative position and length of the chapter membership. The seating chart of the chapter members can be seen in figure 4.4, below. Throughout the Mass, members of the chapter including the priest, deacon, subdeacon, and singers would need to move to and from the altars or lectern for performance of their liturgical duties.[402] Hence, the Mass was a dynamic affair in which singers and listening members of the chapter changed locations and, thus, their relationship to the sources of sound and its reflective or absorbing materials.

[402] John Harper, *The Forms and Orders of Western Liturgy From the Tenth to the Eighteenth Century* (Oxford: Clarendon Press), 121. See also: David Hiley, *Western Plainchant: A Handbook* (Oxford: Clarendon Press, 1993), 1-45.

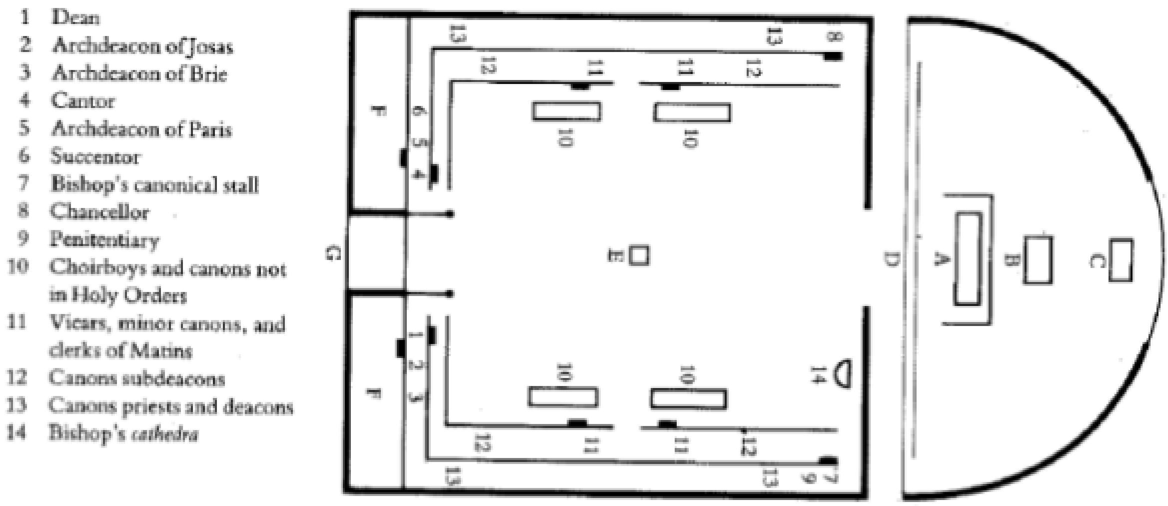


Figure 4.4 Seating chart of Notre-Dame chapter within the choir space. Image Credit: Craig Wright, *Music and Ceremony at Notre Dame of Paris, 500-1500*.

The height of the vaults most affected the acoustics and thus the aural feedback. The immense vault height (32.71 meters), as examined above, caused long reverb times and late reflections that required a great sound volume to balance the direct and reverberant sound in the choir. As the acoustic study results reveal, it would have taken far more than four voices to produce enough direct sound to match the reflected sound.[403] Because of the imbalance of direct and reflected sound, listeners of the chapter would have been very aware of the overhead vaults, which is shown by the center time values. Center time (seen below in figure 4.5) measures the ratio between the "summed products of energy components of the arriving reflections and their corresponding delays to the total energy."[404] High center times, such as those in figures 4.5 and 4.6, indicate that there was a high spatial acoustic impression. In the figure below, the x-axis indicates the Center Time values of the choir space in milliseconds

[403] See "The Results" in Chapter Three, particularly the Direct and Total SPL levels and Sound Strength measures for one, two, and four voices.

[404] *EASE 4.3 Tutorial*, 241.

and the y-axis represents the percent of the space covered by that Center Time value (the greater the percentage the more area covered at that value across the floor plan). The center time values for the male vocal range are 145-291 ms, with a prominent value being 237.86 ms for four voices versus 249.3 ms for a single voice. The high values with four voices and even higher values with one voice are due to the low direct sound levels in the choir, making the listener more aware of the reverberation. Therefore reverberation and late reflections from the vaults produced important aural feedback to all listeners (including the singers) in the choir.

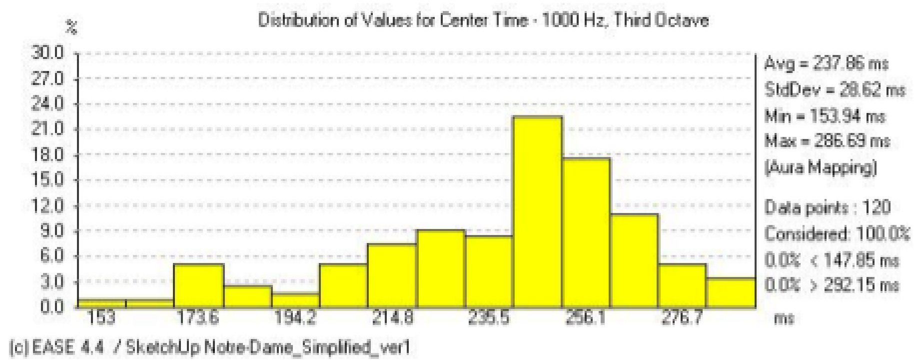


Figure 4.5 Center Time values for four voices.

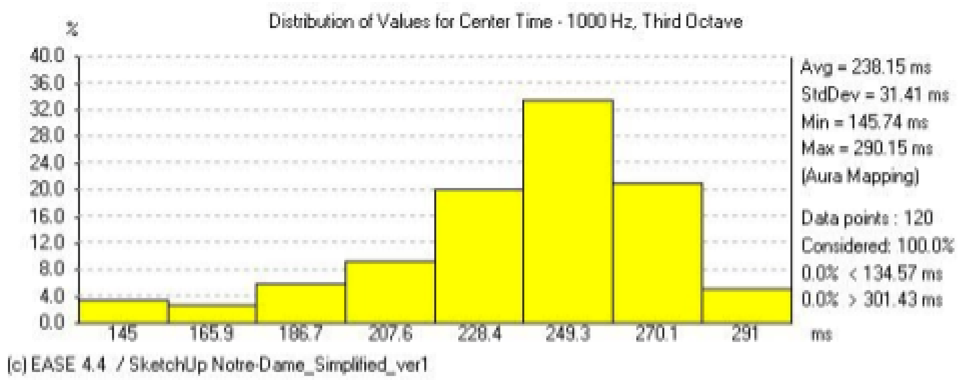


Figure 4.6 Center Time values for single voice

The change in sound volume for the singing practices within Notre-Dame's choir changed whether acoustic location or proximity to the singers was the more important key to well-balanced aural feedback for a listening member of the chapter. At soft overall sound levels close proximity to the singer or singers was necessary to receive strong enough direct sound to offset the reflections, poor clarity, and the loss of definition and articulation in the choir. Especially for one- and two-voice settings, being close to the singer(s) would have been pivotal for the sonic experience. A soloist had the smallest range for balancing direct and reflected sounds, and so, listeners needed to be within a few feet of the soloist for improved direct sound. Greater volume from four singers would have extended clarity and definition farther from the ensemble, with the number of chapter members reached with balance depending on the location of the singers, as seen below in figure 4.7. Clarity values in close proximity of the singers improves by 6 dB (from the minimum value -5.42, represented by the grey area in fig. 4.6, to the maximum of 1.34, represented by the dark blue). Definition additionally improves dramatically, shifting from minimum to maximum values of over 50% (see fig. 4.8 below)—the measure preferred by acousticians.[405] In figure 4.8, the definition measures are mapped onto the floor plan with the aerial view showing the highest definition values of 54.1 directly in front of the sound source, fading to the lowest value of 12 (shown as pinks and reds) at the periphery of the image. Being close to the singers would not only help the chapter to follow the singers, but also to stay in time with chanting, and to join the singing at the correct moment. Being close to the singers improved aural feedback, however the singers changed location depending on the type of polyphony being performed and the feast day.

[405] *EASE 4.3 Tutorial*, 240.

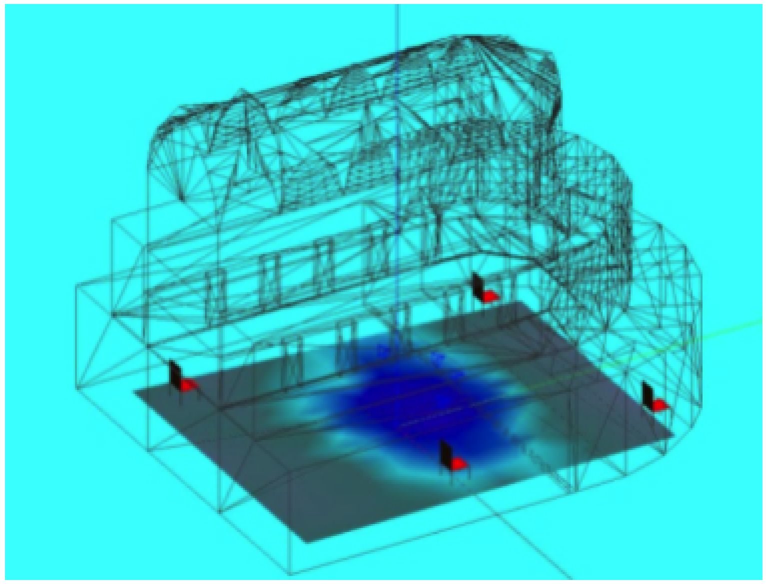
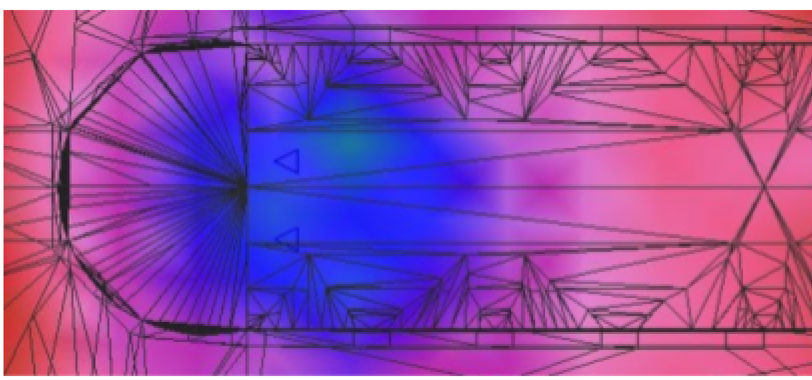


Figure 4.7 Clarity visualization for four raised voices. The dark blue field represents the highest clarity value, the light blue the next highest, and the grey the lowest clarity values. The sound sources in this simulation are standing in the center of the dark blue field. Image Credit: Schwartz, Acoustic Simulation 2020, *Ease AFMG 4.4*



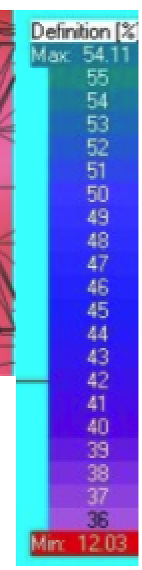


Figure 4.8 Definition visualization for two raised voices. The small green spot just in front of the sound source represents the highest value of 54.11. The dark red around the edges represents the lowest value of 12.03. See the color chart to the right for the full array of values.

Sitting beneath the vaults of the sanctuary, the Bishop had one of the best potential listening locations. When present, the Bishop was the most important figure and listener to address (especially before the death of Maurice de Sully who was responsible for getting the new cathedral built). At his spot in the choir stall, to the West on the South side of the choir, the Bishop would have experienced some of the most reverberant aural feedback in the choir. His proximity to the singers standing at the altar is even more of a benefit as it put him closer to the direct sound. When the singers were in the center of the choir, the Bishop would have had the most resonant aural feedback when there were at least four voices singing, and this could have been augmented further by moving the singers a few steps towards the altar. Moving the singers would insure the Bishop received increased direct sound to improve clarity. If a solo singer or the singers of an organum duplum setting were standing in the middle of the choir, the sound they produced wouldn't have been adequate to enfold the Bishop's seat within the higher clarity values. Though the *organum* singers could again move closer to the Bishop, it seems less likely that they would have moved the soloist because of the flow of the liturgy and needs of the chapter as a whole. The force of the group chanters were, afterall, directly in front of or next to the soloist at his choir stall. Overall, the Bishop's seat was in a good location to hear the resonance of the stone vaults and the polyphonic singers, particularly those standing at the altar; this resonance would have been an enjoyable feature with thicker polyphonic textures.

In contrast to the Bishop's location, those at the opposite end of the choir were never in an ideal listening position. If the chapter of the late twelfth century sat with the same position as those of the fourteenth and fifteenth, the members of the chapter directly involved with overseeing and controlling musical practices would have had some of the worst seats in the choir. The Dean, Cantor, and Succentor all sat at the west end of the choir, seated close to the wooden wall but nearly under the center of the vaults. Every step the singers took towards the Bishop moved them farther away from those at the Western end of the choir, worsening their aural feedback. The Cantor and Succentor would have received weaker direct sound levels, increased late reflections, and decreased sound clarity and definition with a high articulation loss as a result of the distance to the singers. Direct sound took the longest to reach them, especially with singers near the altar, further shifting their perception of direct and reflected sounds. Being closest to the wooden wall, seating positions to the West also were closest to construction and its noise. It is ironic that those in charge of music at Notre-Dame had the worst aural feedback, perhaps encouraging the use and inclusion of new musical textures to improve the overall listening experience.

Central location in the choir provided the members of the chapter responsible for the majority of the singing with one of the best listening experiences. Their location put the choir boys and matins clerks directly in front of the soloist intoning the chant from his choir stall, close to the singers standing in between the choir stalls in the center of the choir, and closest to the center of the space. Such an advantageous location put these listeners in proximity to much of the direct sound being produced during the Office and Mass. Because the choir boys and lowest ranking members of the chapter sat almost directly in front of the soloist, they would have been the first to be reached by direct sound, particularly when a soloist was intoning the chant. Their proximity to the sound source would have improved clarity and definition of the sound, and therefore, comprehension of the text. However, the choir boys' and other low ranking chapter members' location under the vaults also meant that aural feedback included a significant amount of echo and late reflections when the polyphony was performed at the altar steps (see figs 4.1 and 4.2: echo reflections focus in front of the singers), impacting the perceived balance between direct and reflected sound and, hence, their ability to join in the chant at the correct moment. Regardless, throughout the Mass the choir boys and clerks without Holy Orders would have been most able to join the chant in time with the soloist and to help continue the service in the correct pulse.

The variation in listening experience has interesting implications for changes of musical practices during construction. Liturgical practices dictated that the singers should be located in specific locations, depending on what they sang and their role in the Mass. The soloist stood at his choir stall or perhaps on the stairs of the choir stalls, whereas the singers of polyphony stood in the center of the choir (between the two choir stalls) or at the altar steps. To best adjust to the acoustic environment throughout construction, it seems highly likely that moving singer location close to the altar would have been needed or at least explored so as to cater to the higher ranking members of the chapter such as the Bishop. The aural feedback heard by the listeners, particularly those of importance, would have been a consideration affecting the musical practices within the choir space. So, too, would changes have been needed to improve sound production to aid the chapter members' ability to hear and join the liturgy at the appropriate times to continue services without unnecessary delay. However, the singers would have needed to adjust more than just their location within the choir for their sound to best fill and resonate within their new choir space.

Singing Polyphony: Location, Voices, and Musical Techniques

More than any other members of the chapter, the singers needed to understand how their location and polyphonic texture interacted with the acoustics of the choir. As discussed above, intoning a chant, beginning a new chant, or switching between chant and polyphony all posed a challenge to the singers. Performers of each polyphonic texture—whether organum *duplum, triplum or quadruplum,* or discant—would have faced different acoustic advantages and limitations within the choir space that impacted performance. As will be examined below, elements of the setting including the number of singers, rhythm, repetition, and vocal range all impacted the aural feedback and sonic effects of the performance. To smoothly conduct a festal Mass, such as the Mass for Christmas Day, singers at Notre-Dame would have needed to be aware of how the musical features of the polyphonic settings interacted with the acoustics and how their location impacted their aural feedback in order to make the appropriate musical adaptations.

In what follows, I consider the Mass for Christmas Day as a case study, because of its elaborate and dynamic liturgical practices. Mass for Christmas Day involved a near constant shift between soloist and group chanting or polyphonic singing and chanting. Archival sources indicate a limited use of polyphony such as organum in the early twelfth century.[406] Therefore, unless polyphonic textures were improvised (unwritten) or later written into manuscripts, more of the liturgy involved group chanting than polyphony. The Mass for Christmas Day consisted of eleven chants including both Ordinary and Proper chants. Of the five Proper chants of the Mass, only the Gradual

[406] See Chapter One, and Wright, *Music and Ceremony,* 102-109.

and Alleluia would have been sung using polyphony.[407] The restricted use of polyphony gave it a special place at Notre-Dame, making it especially important that it sound good throughout the acoustic environment of the choir. This, of course, provided challenges to performance given the intrinsic difficulties of its singing and the acoustic variability throughout the space.

Multiple aspects of the musical practices at Notre-Dame could be controlled within the choir, from individual musical features to altering the hangings within the choir space. Singers could modify elements of each type of polyphony, such as melody, tempo, and rhythm through improvisation and practice adapting their singing to their aural feedback. Singers needed to be aware of their aural feedback as they changed locations to account for the changing reflections and echo times throughout the space. Additionally, they would have needed to consider how the various polyphonic textures of *organum* and discant interacted with their acoustic environment. The change in number of voice parts from *duplum* to *triplum* or *quadruplum* and the differences in rhythmic texture and melodic and harmonic coordination provided vastly different musical techniques for adjusting to and working within the acoustics of the choir space. In order to explore a more holistic understanding of how polyphony might have interacted with the acoustic environment of the new choir, I consider the aural feedback in different singing locations and the sonic effects of *organum duplum, triplum and quadruplum* settings, and discant polyphony.

The singer's or ensemble's aural feedback was impacted by their location within the choir, just as location affected the listener's experience. The singer's position would

[407] Elements of the other Hours of the day were also sung with polyphony, including the *Benedicamus* of Vespers.

have changed the amount of sound absorbing materials near them, their perception of overhead reflections, and the echo time they would have experienced. Each location within the choir would have produced a new aural experience depending on the number of singers and thus level of sound production. The singers' ability to make adjustments was complicated by which polyphonic texture or voice they were performing. Regardless of the type of polyphony being performed or the number of singers, the singers' abilities to adapt to the performance space hinged upon the aural feedback received, which was ultimately governed by their location.

Singing at the altar would have provided polyphonic singers the opportunity to hear themselves most clearly. Standing at the steps of the altar and facing the rounded hemicycle wall, polyphonic singers were separated from the majority of the chapter, and were closer to the internal stone walls of the choir. Because the singers' and chapters' bodies absorb sound, fewer bodies in the area near the altar meant less sound absorbing materials, compared to singing in the center of the choir. The altar and Sanctuary, however, would have been decorated with numerous fabrics and wall hangings, meaning that the singers were not singing to bare stone walls and that some sound absorption was occurring. Facing away from the chapter would have created an insular singing experience in which the singers could focus more easily on their voices, the ensemble, and their aural feedback. Standing at the altars would also have provided singers with more lateral reflections from the stone walls with which to hear themselves. Further, the half-dome vault under which the singers stood reflected sound waves back into the rectangular bays of the choir, meaning that many of the late reflections and the most prominent overhead reverberation would occur behind the singers back.[408] Singing

[408] This is supported by the EDT, T10, and Echo visualizations for the two and four voice simulations.

at the altar, then, would mitigate some of the effects of the echo on the singers. Their proximity to their fellow singers and their aural feedback would balance their direct and indirect sound, and would have allowed singers to better focus on the sonic effects of the polyphony they were performing. The area near the altar, then, would have been a good location for sonic experimentation by the singers.

Singers would have been more aware of the full choir space while standing in the center of the choir. Standing between the choir stalls and rows of their chapter members, singers were in the thick of things in the choir both physically and aurally. First, being close to the other chapter members could have meant that more extraneous noises were audible as members moved, coughed, talked, or entered the chant off time. Noise from chapter members would have been added to the aural feedback in the space immediately adjacent to the singers. Second, the singers were close to the sound-absorbing bodies of the chapter and in front of the choir stalls. Direct sound reached the listeners quickly, but some was absorbed by the chapter members and some was reflected quickly from the choir stalls behind them. Additionally, central location meant that the singers' aural feedback was more similar to that of their fellow chapter members. Understanding the aural experience of the listeners in their proximity likely allowed the singers to tailor their sonic and musical adjustments to the chapter. Third, singers standing beneath the vaults were in an area with more noticeably long reverb and later echo times. Singing in this position meant the singers of polyphony could better interact with the resonance and overhead reverb of the performance space. As such, standing in the choir could have been a good location to fine tune or balance a performance or new rhythmic texture.

Many singers, including soloists and group chanters, sang from the choir stalls that lined the north and south walls of the center aisle. On feast and non feast days alike, all the singers likely would have sung various parts of the Mass from their places amidst the choir stalls. Soloists standing within the stalls (or on the stairs between the aisles of stalls) would have found singing slightly easier because they were close to their audience. A soloist facing the opposite choir stall would have found sound production and projection to the bulk of the chapter more effective because they sang directly toward members across the aisle and those farthest from them. Additionally, being next to the other chanters would aid pulse and tempo for group chanting. Group chanters standing within the choir stalls were likely acutely aware of, and tuned into those around them as they were grouped close to one another and faced the chapter members opposite them. Chanters in the stalls were placed advantageously for ensemble singing. Their proximity to each other would have aided them in singing together in time with one another within the acoustic environment of the choir.

Soloists and chanters would have faced significant acoustic challenges. As mentioned, low volume levels of the soloists made poor clarity, late reflections, and echo highly detrimental to the chapter's ability to accurately join a soloist (or polyphonic ensemble) for chanted sections of the Mass. The fast lateral reflections in the choir (latest arrival time of 19 ms (0.019 s) versus an Initial Time Delay Gap gap of 2.11 ms (0.00211 s)) meant that listeners at the far end of the choir would receive their first lateral reflection almost simultaneously with the initial sound, whereas late and variably timed overhead reflections and echo could distort their sense of tempo and pulse.[409] As

[409] For more arrival time measures see Chapter 3 "The Results." The Initial Time Delay Gap measures were also calculated in Schwart's simulations but were not included in Chapter 3.

such, it would have been very easy for listeners far from the singers to be distracted by the late reflections causing difficulty in following the soloist. Similarly, the noted acoustic interferences in the choir would make smooth transitions between solo singing to chanting difficult. Chanters likely would have needed to watch for a cue from the soloists to indicate pulse and the proper timing to enter, rather than waiting for sound to reach their ears. Singers and chanters at every location in the choir would have needed to focus their attention on physical, rather than aural, cues in order to sing together accurately.

The prominent use of responsorial chanting (alternating between soloists and group chanting) in the liturgy placed a significant sonic burden on solo singing within the choir. There were, however, at least two practices of the day that could have helped to boost sound production for all chants. Musicologists are aware of two improvisatory practices and techniques for embellishing the chant that could replace solo singing: improvised parallel organum and troping. Parallel organum was an improvisatory technique wherein singers doubled the soloist's chant sections using parallel motion at the interval of a fourth, fifth, or octave. Polyphonic tropes were added sections of new music and new words within a preexisting chant; although the tropes didn't replace the entire chant, they could add sections of increased sound production.

The singers at Notre-Dame could have used either parallel organum or tropes to replace solo singing during construction. In some cases (like simple Mass or low rank feasts) soloists were possibly left to struggle with intoning the chants so that the flow of the liturgy through the Mass remained simple. For Mass associated with important feasts, however, the use of additional polyphony through parallel organum or tropes would have augmented the performance. Additionally, the need for increased sound production (especially in later stages of construction) would have made replacing or bolstering solo singing an appealing solution for the singers. By the twelfth century, parallel organum was a well established practice, mentioned as far back as the *Musica Enchiriadis* from the tenth century. Such a practice would have been a simple technique for Notre-Dame's singers to use to replace all solo singing in the chants of the Mass with duets. Sonically, the parallel intervals would not have been out of place in a Mass that also featured discant or *organum quadruplum*, perhaps making parallel organum an even more appealing solution for increasing sound production. The addition of tropes would not have replaced solo singing completely, but would have added more sound either to emphasize text at important moments of the chant or to boost sound production at the moments in which the chanters prepared to join the soloists. Whether improvised or not, adding polyphony to the solo sections could have been a technique used to both embellish the chant and to improve sonic conditions within the choir.

As a tool to benefit sound production, especially during construction, improvisational skills would have been beneficial for singers. Not only would improvisation have enabled singers to create new polyphonic settings to best suit the desired sonic effects and experience, but improvisation gave them a tool to adjust to aural feedback in the moment. Although rehearsals took place at Notre-Dame in the twelfth century are not documented, polyphonic settings certainly would have been rehearsed and aspects of the performance, such as the insertion of a discant clausula, certainly would have been planned.[410] The singers would have decided in advance who

[410] No such documents that mention rehearsals are noted in any studies of Notre-Dame polyphony, however the rigor of the singing practices and high expectations from chapter officials (Discussed in Chapter Two and in the Introduction) suggest that they must have taken place. Rehearsals may have

would be singing particular lines in the texture, and also which harmonies to use at changes in syllable. I posit that improvisation would have been the best way to effect quick musical changes while adjusting to a changing acoustic environment. During the early period of adjustment in the choir, it would have been hard to fault the singers as they worked out how to cope with the new space, particularly for issues such as tempo. Being some of the lowest ranking members of the institution's hierarchy, singers likely did not have the authority to make permanent musical changes, but they couldn't have been stopped during services. This is supported by records of reprimands, including citations to Matins singers' for singing too slowly during Mass.[411] Perhaps the authorities of the chapter, understanding the challenges, would have allowed them more musical flexibility. This is to say that the techniques used to adapt polyphonic settings as we know them today could have been plentiful and changed in the moment as necessary depending on material conditions.

Each texture of polyphony would have benefited from the use of repetition and longer rhythmic values in order to improve clarity within the performance space. Whether by altering the melody to include more repetition, tones, or melodic gestures, or by using longer rhythmic values (such as the double long) every texture of polyphony could be modified to adapt to the singers' aural feedback. Melodic and harmonic repetition of an interval in particular (see the examples in Chapter One) could have been used to alleviate the sonic impact of several acoustic characteristics, improving clarity and coping with the echo. In all polyphonic textures, singers could have used

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additionally needed to take place during the late twelfth century to test new polyphonic settings before the Feast day.

[411] Wright, *Music and Ceremony*, 237-240.

repetition of intervals or tones to best compensate for the long reverb times and echo.[412] Both acoustic features caused a sound to last for several seconds within the vaults and then return as an echo. By using repetition, the reiterated tone could blend with the existing reflections rather than clashing. Repetition used in this manner would have been especially beneficial for creating clear tonal feedback for all listeners. Moreover, repetitions would have reduced the impact of poor clarity and echo because listeners wouldn't need to hear as many individual notes in the melody. As such, singers' use of melodic and harmonic repetition would have well suited the acoustics of Notre-Dame's choir.

Although not a technique specific to polyphony, sustaining vowels of particular syllables would have had benefits within the acoustics of the choir. In both *organum* and discant settings, syllables of the setting's chant text are frequently expanded over long melismas or rhythmicized melodies. The ends of musical sections or discant clausulae would then move through text more rapidly, making up for the extension of earlier vowels. Sonically, the reduction of text in some sections means that the acoustic clarity would impact only comprehension of the musical features instead of affecting comprehension of both music and text. Equally as important, sustaining the vowels in polyphonic settings also reduced the impact of articulation loss.[413] In moments when more extensive text declamation was needed, singers could use slower rhythmic values to extend tones with less use of melodic embellishment to help listeners' comprehension. Sustaining vowels, a feature of *organum* and discant, would have

[412] A discussion of repetition of tones, intervals, and melodic content or contours in Notre-Dame polyphony can be found in Chapter One. Frequent repetition of tones and intervals can be heard particularly in the *triplum, quadruplum*, and discant settings in Notre-Dame's repertoire.

[413] Articulation loss is discussed in "The Results" in Chapter Three.

served as a technique for reducing the impact of clarity and articulation loss in the new space.

The intricacies of each polyphonic texture enables varying amounts of melodic, harmonic, and rhythmic changes to be made without impacting the performance. *Organum duplum*, for instance, involves less strict coordination between the organal and tenor voices, allowing the soloist singing the duplum voice to make numerous changes in melodic contour or tempo to improve aural feedback. Conversely, the coordinated rhythmic measures of *triplum, quadruplum*, and discant settings required harmonic and rhythmic agreement between the voice parts. The acoustic challenges of the choir required the singers to consider several different musical, sonic, and acoustic features simultaneously in order to create the most comprehensible and best sounding polyphonic performance.

Singers of *organum duplum* faced many acoustic and sonic challenges. The rhythmic practices of *organum duplum* are less well-defined than later options, and therefore was a very distinct musical practice at Notre-Dame judging from surviving notated sources including W1 and F. At a minimum, *duplum* settings were performed with one singer on the upper voice part and a second on the held tenor. As discussed in Chapter Three, the two voices would have struggled to produce adequate sound levels. Additional singers could have been added to the tenor line, but this would only have increased sound production of the held notes minimally.[414] Further, the florid melismas of the *duplum* voice were ill-suited to the long reverb times of the choir. Hearing the elaborate melodies would have been difficult with the low clarity and overwhelming

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[414] For more discussion of *organum duplum*, see “Notre-Dame: Source Materials” in the Introduction Chapter, and Chapter One.

resonance above the singers. The soft, ephemeral melodies would have been muddied by the echo, if not addressed. Further, if the tenor voice was doubled, all singers could have struggled with ensemble balance. Two tenors, especially if singing in the melodic range of the duplum voice as we see notated in many settings, could have been overpowering.[415] However, the singers also had many options for adapting to their aural feedback in the choir.

Because the voices moved independently, individual singers of *organum duplum* could have adjusted almost every aspect of the setting on their own. To work with and account for the echo, singers could have improvised or constructed melodies that included more repetition, or that employed a contour that produced consonances with the echo. Rhythmically, singers of the organal voice also could have used longer rhythmic values to further control reflected sounds and the resulting harmonies. Tempo and pulse of the setting also could be made to ebb and flow to adjust to transitions between rhythmic textures, such as transitioning from a melisma to a discant clausula, or from polyphony back to plainchant. Finally, to counter the issue of balance between an upper voice and a doubled tenor, those singing the held tenor ideally would be singers capable of singing an octave below the duplum singer. The lower octave would not only help aurally distinguish the voice parts but also would produce a different acoustic response than the higher octave.[416] Though *duplum* settings had limited overall sound productions, singers could have altered the features of the polyphonic setting during performance to tailor the aural feedback to the acoustics.

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[415] The similarity of vocal range between the voice parts can be seen in the examples discussed in Chapter One, and in the notation of W1 and F.

[416] See "The Results" in Chapter 3 for the difference in T values, clarity, definition, and EDT between 125Hz and 250Hz. See also Appendix II.

The sonic advantages of *triplum* and *quadruplum* settings were a result of the increased number of singers and accompanying sound production, as well as the rhythmic structure. The held tenor provided a sonic foundation and almost constant source of sound production to carry the upper voices. Sound production likely was increased on feast days of highest importance by doubling or tripling the voices. Additionally, the rhythmic texture in the upper voices of the settings coordinated the singing of intervals, therefore slowing the melodic production. Alternating long and short rhythmic values and especially placing emphasis on the long values would help control what was emphasized in the reflection and echo of the choir. In addition, using repetition could sustain a tone or interval in the direct sound, the reverberated sound, and echo. Further, tempo could be adapted to suit the aural feedback. If singers used a lot of repetition (again of tones or melodic gestures), tempo could be increased with less detriment to comprehension of the setting because the same intervals or tones would be resounded to match the echo and reverberation within the space. If less repetition was used in the upper voices, however, singers would have needed to slow the tempo to avoid muddiness of sound and clashing harmonies.

Sonically, the musical features of *organum triplum and quadruplum,* including the rhythmic texture, had the potential to limit or even detract from the performance and aural feedback. Compensation for the space's echo was particularly important for the thicker textures of *triplum and quadrplum*, requiring control of tempo, rhythmic measure, and melodic contour in each voice to achieve clarity. When aural feedback became jumbled, a well-trained and experienced polyphonic ensemble likely could have varied their rhythmic measure in each voice part. Even so, some limitation of the flexibility of individual voice parts stemmed from the need for all voices to coordinate harmonically above the tenor. In more contrapuntal settings or sections using less homorhythm among voices, singers likely struggled with comprehension and clarity of the setting.[417] The long reverberation times would have distorted the melodies of each voice part, muddying the aural return to the listeners.

The increased number of voice parts in *organum triplum* and *quadruplum* would have created more potential balance issues compared to *organum duplum.* In *triplum* and *quadruplum* settings the upper voices (if very contrapuntal) could compete not only with each other, but also with the tenor. If the number of tenor singers equaled or exceeded the number of upper voices, tenors could be overpowering, especially if all were singing in the same melodic range. O*rganum triplum* and *quadruplum,* however, could have the advantage of rhythmically unified upper voices that would multiply sound production above the tenor voices. Conversely, if there were only a single tenor singer, the opposite balance issue could arise in which the upper voices become overpowering, burying the held chant tones of the tenor part. One effective solution for such balance issues, similar to *duplum*, would be for the tenor and upper voices to sing in different octaves or distinct melodic ranges.

The large sound production of *organum triplum* and *quadruplum* ensembles, compared to *duplum,* provided more flexibility in location the singers could perform. With three to eight singers depending on the feast day and the number of tenor singers, the direct sound of *triplum* and *quadruplum* settings would have reached a large number of listeners in the choir. Larger polyphonic ensembles could have stood in the center of

[417] See the discussion of *Terribilis* in Chapter One.

the choir and have produced a better sonic balance between direct and reflected sound for most listeners in the chapter than *organum duplum*.

Polyphonic singers performing discant would have experienced many of the same advantages and drawbacks as when singing other polyphonic textures. The rhythmic coordination of discant served to increase sound production through active articulation in all voice parts. The regulated rhythmic structure, however, limited the melodic flexibility of discant clausulae and settings. Similarly to the upper voice of *organum triplum* and *quadruplum*, the voice parts of discant needed to be coordinated harmonically to avoid dissonance; therefore only some modifications to the melodic line were possible (especially without an experienced ensemble). The rhythmic structure of discant is better suited to incorporating—and adjusting to—the echo. The longer rhythmic values together with repetition and tempo control would allow the echo to be incorporated into the surrounding texture, adding or doubling tones or harmonies. If, however, singers did not employ rhythmic values to match the echo, their lines would quickly become jumbled and highly dissonant. Discant's measured tenor also would provide an advantage to singing with an echo. By incorporating rests in all voice parts, particularly in unison passages, singers would allow some of the reflections and echo to clear before beginning a new phrase.[418] The echoes would fill the rests, and the use of frequent rests would help to limit and reduce the effects of sound reflections and the echo. Whether singing discant on its own or incorporating a discant clausulae into an *organum* setting, discant provided singers a new set of tools to balance direct and reflected sound.

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[418] The sonic benefits of coordinated rests, and the frequency of such a technique, can be seen particularly in my discussion of *Sederunt* in Chapter One.

Singing polyphony within the choir space would have required special attention to be paid to the aural feedback in order to make the necessary adjustments for each polyphonic texture. *Organum duplum, triplum, quadruplum,* and discant settings all had different sonic effects, advantages, and challenges. The number of singers, their vocal ranges, and their locations within the choir all affected aural feedback to both signers and listeners, and the ability to comprehend the setting. The above examination reveals that while all textures and types of polyphony could have been performed and made to fit the acoustic features of the choir, the more rhythmic textures were better suited to the acoustics of Notre-Dame from 1182 until the wooden wall enclosing the choir was removed around 1208. Indeed, the rhythmic structures of discant, found also in the *triplum and quadruplum* settings, would have been more appropriate for alleviating and working with the reverberation, echo, and volume levels within the choir than the melismas of *organum duplum*.

Conclusions

The insularity of singing within the choir for at least the twenty years right after the completion of the choir allowed the chapter and its singers a substantial period to expand their musical repertoire to suit the new acoustics. And while the chapter continued to sing genres of polyphony including plainchant and *organum duplum* created before construction of the new cathedral, during construction singers expanded their practices to include *organum triplum* and *quadruplum* and discant settings. Singing within just the space of the cathedral's choir gave singers an opportunity to adapt their musical practices to best suit the new space and the aural needs, or demands, of the chapter officials. Sonically, all the documented polyphonic textures could have been performed in the choir but each needed to be adapted to the acoustics of the choir. The echo, the poor clarity, long reverb, and a high center time impacted the melodic, harmonic, and rhythmic features of every texture of polyphony. So too, did the location of the singers and listeners, which presented further repercussions for the polyphonic textures and their comprehension. As stated, the smaller the number of singers the closer they needed to be to the chapter and, if possible, to the most important members. The importance of the listeners' proximity to the sound source had implications for each texture, as proximity changed listeners perception of multiple acoustic characteristics. Furthermore, the location of the singers also affected their own aural feedback and how they would have adapted and performed polyphony. The acoustics of the choir altered the performance and perception of every musical performance and every type of singing that was required of them.

Examining and understanding the acoustics of the incomplete cathedral, during the time in which the rhythmic experimentation of the late twelfth and early thirteenth centuries took place, presents us with a vastly different relationship between the repertoire and Notre-Dame cathedral. First and foremost, it reconnects us to the performance conditions of the cathedral as it might have stood at the end of the twelfth century. Still in the early stages of construction between 1182 and 1208, the choir stood alone and was enclosed by a wooden wall prior to the completion of the transept and eastern bays of the nave. The chapter may have continued to worship and perform within the enclosed choir until the nave walls were completed no later than 1220. Performance conditions within the choir, as outlined above and in Chapter Two, were less than ideal as construction noises and the removal and addition of building materials continued to affect musical and liturgical practices until the 1320s. Second, analyzing the acoustics of the choir reveals the differences between the incomplete and complete cathedral space. The choir's reverberation time would have been less than half that of the complete cathedral. The clarity measures, while not high, are consistently higher than for the complete cathedral. If I were able to numerically compare the measures of all the acoustic features discussed in Chapter Three between the complete and incomplete cathedral, it stands to reason that many features would have been markedly different. Third, exploring the sonic impacts of acoustics on polyphonic textures elucidates changes derived from the practical necessity of new rhythmic textures, as opposed to viewing them as simply the result of notational advancement or aesthetic choices. The new height of the vaults produced longer reverberation, more overhead reflections, and likely a more prominent echo than the previous church space (if it had one at all). While medieval singers might not have known the scientific terminology of these sonic effects, they certainly would have had aural knowledge of them.

The musical practices at Notre-Dame would have been more dynamic than what was possible to record in manuscripts. The choir was the performance space of an ever adapting polyphonic repertoire. Singing in the acoustics of the choir, and later, the full cathedral, combatting the continuous interruptions brought about by construction, all the while incorporating new singers among the clerks, all provided challenges that would have tested the skill of the singers. The versions of surviving polyphonic settings recorded in manuscripts communicate an advanced musical and sonic awareness among both the singers and composers. The acoustics of the choir was a soundscape wrought with the possibility of incomprehension and muddled sounds. Although the chapter may not have been able to hire singers on talent alone, they certainly needed capable singers.

While the cathedral was under construction, the musical practices at Notre-Dame would have required trial-and-error and sonic experimentation in order to maintain a practical, functional, and audible polyphonic repertoire. This study proposes that the shift from melismatic organum to discant textures began for just this reason. And, I posit that this shift began in the 1180's, when the chapter entered the new choir. The evidence—such as the increased amounts of discant clausulae, discant settings, and polyphonic settings with rhythmic measure in the upper voices—indicates that singers were aware that change was necessary to adjust to their new acoustic environment. The coexistence of oral and written practices, of improvisation, composition, and planning meant that the chapter's singers had the tools needed to adapt their musical practices to best suit the new cathedral.

Examining how sound reacted within the cathedral space and the relationship between the construction history and performance provides a new context for interpreting the building's materials, performance conditions, and the repertoire within the cathedral. For instance, the need to revise the *Magnus Liber Organi* relatively quickly after it was first compiled can be linked directly to the rapidly changing repertoire appropriate to the new acoustics, and the need to include more measured and discant settings as well as discant clausulae that can be added to existing organal settings. Accounts of listening to polyphony within Notre-Dame, such as the reaction from John of Salisbury, are better interpreted within the acoustics of the choir and how easily those acoustics could have led to incomprehensibility. Finally, materials that communicate performance practices, including Odo de Sully's 1198 edict, have further significance when considered as markers of the chapter's adaptation to the new choir. Reconsidering accounts, archival records, and the repertoire from the perspective of the developing practice and construction provide new insights into the performance practices and polyphonic development at Notre-Dame. With further research, these kinds of reconsiderations could lead to revised timelines and deeper insights into the surviving repertoire.

While there are many ways in which I would like to expand my research, this dissertation lays the foundation for reexamining the development of Notre-Dame polyphony. The construction history of the cathedral cannot be separated from the development of Notre-Dame's polyphonic repertoire. For the many years that musicologists consider to have been Notre-Dame's most influential period, the chapter wasn't worshiping within a completed space or perhaps not even within their own worship space at all. Even once they moved into their new choir, further construction and interruptions to the chapter's soundscape were far from over. The immense change in the overhead vault height and volume of the cathedral alone, plus the frequent addition and subtraction of sound-dampening or sound-reflective materials must have had an impact on liturgical and musical practices, as I have argued throughout the dissertation. The now lost acoustics were central to the polyphonic repertoire and musical practices at Notre-Dame. Today's scientists, acousticians, and masons can rebuild what was lost in the fire of 2019, but we cannot recover the sounds of singers in the choir in 1198 let alone the acoustic experience of the medieval space. We should, however, let the cathedral’s history and acoustics inform how we hear the polyphonic practices of the twelfth and thirteenth centuries.

Appendix I

The following table is an outline of the construction history of Notre-Dame of Paris and donations made to the cathedral or chapter. For each construction milestone or construction item the secondary source is indicated that supports the datings, along with the relevant primary source(s). Also included in the timeline are the Bishops of the chapter and architects involved in the cathedral's construction. Please note that this timeline is not comprehensive of all construction and donations made to the cathedral. Rather, I have paid particular detail to the construction up to ca. 1250 and chapel donations up until ca. 1340. In the secondary and primary source columns, the author's name and page number are given. For instances in which multiple texts by the same author are being cited, the year is also given to indicate the source. Full citations can be found in the works cited at the end of this appendix for further clarification.

Date	Construction Item/Area Completed	Donations	Secondary Source (Page Number)	Primary Source (Page Number)
1160	Maurice de Sully became Bishop		Erlande-Brandenburg (55). Tallon/Sandron (16). Aubert 1909 (7).	Mortet and Deschamps (111). Caesar of heisterbach in Muldrac (91-92).
		Maurice de Sully Donates 100 pounds to the fabric	Erlande-Brandenburg (50)	
		William of Barres gives 50 pounds to the fabric to the church	Tallon/Sandron (22)	
ca. 1160		Louis VII gave 200 pounds to the fabric	Tallon/Sandron (22)	
ca. 1163	Construction began		Aubert 1909 (30/39). Erlande-Brandenburg (54)	Testimony from Jes de Saint-Victor in Mortet (41-43). *Gallica christiana* VII, vol. 71.
	Choir was built from outside in (inside walls lagging 4-5 bays behind outer)		Bruzelius (546)	
	Hemicycle built north to south straight, then back to north straight		Bruzelius (543). Clark (1985, 35). Kimpel (195-222)	Bruzelius Archaeological study (543)
	Transept possibly not planned originally		Bruzelius (548-49). Erlande-Brandenburg (65). Viollet-le-Duc, IX (22).	Bruzelius Archaeological study (548 & 550)

	Tribune built north to south		Bruzelius (548-52)	Bruzelius Archaeological study (549-50), see drawing (552)
ca. 1163-64		Documents of House purchase		Mortet (83)
1160s or early 70s	Work on Tribunes began		Bruzelius (549-50)	Bruzelius Archaeological Study (549-50)
	mention of stair		Tallon/Sandron (43). Erlande-Brandenburg (58).	
ca. 1170	Flyers introduced		Bruzelius (555)	Appearance of flyers at Canterbury (1176-77)
ca. 1170s	Nave begun while choir under construction		Bruzelius (559-561)	Style of elevation shafts, flying buttress design, understanding of masonry work flow
	Second Master took over construction		Bruzelius (550). Erlande-Brandenburg (62)	
	Elevation - changed by second master		Bruzelius (550). Erlande-Brandenburg (65). Violet-le-Duc, IX (8)	Archaeological evidence of masonry stubs, use of different stone, and variations in the foundation course heights and base designs to indicate transcept that did not extend beyond aisle
ca. 1175-1180		Henri, archbishop of Reims paid for 11 lamps to burn in the choir		Guérard, IV (187)
		Alexander III gave 2 marcs of gold for work on the cathedral		Guérard, IV (170)
		King Louis VII donation		Guérard, I (270-271)

		Barbedor, Dean of chapter, gives 200 livres		Guérard, IV (153)
ca. 1177	Choir complete except for vaults		Bruzelius (555). Tallon/Sandron (38). Erland-Brandenburg (55)	Torigny (68).
1180		Dean Barbedor gives liturgical books with gold and metalwork.	Tallon/Sandron (53)	
		Louis VII gives a gold chalice and 2.5 marks of hold for the mass (about 600grams),	Tallon/Sandron (53)	
		Philip Augustus possibly gives a retable to altar, and	Tallon/Sandron (53)	
		Ingeborg gives a pallium	Tallon/Sandron (53)	
ca. 1182	Consecrated, 19 May, performed by Cardinal Henri of Albano Chateau-Marcay		Bruzelius (555). Tallon/Sandron (46). Aubert (9)	Vigeos (330). *Hitoriens de France*, XVIII, (212).
	Wooden wall enclosing space		Tallon/Sandron (44-45).	
	Implication that vaults are completed at this stage		Tallon/Sandron (63-64). Erlande-Brandenburg (59)	
ca. 1180 to 90	Construction of upper stories of east bays of nave underway		Bruzelius (559)	1186 excavation
1186	Excavation for foundation of western bays of Nave		Bruzelius (559, 562)	Discovery of relics mentioned by Torigny (136). Litigation with St.-Denis, Spiegel (48-50).
ca. 1190s	Third Master took over construction		Erlande-Brandenburg (94)	
ca. 1195-1200	West facade thickened to the west		Bruzelius (562)	Excavations in 1186.
	Facade construction delayed significantly (negotiation of		Bruzelius (562&564). Aubert (34, no. 3)	Mortet (46)

	purchase and demolition of houses)			
end of 12th Century		Dean Barbedor gives a stained glass window with a value of 15 lbs.	Aubert (9).	
		Canon Albert leaves 20 pounds for the construction of choir stalls	Erlande-Brandenburg (50)	Guérard, IV (118). AN LL 290, Fol. 49v
1196-1208	Eudes de Sully was Bishop		Erlande-Brandenburg (50). Tallon/Sandron (55)	
1196		Maurice de Sully leaves 100 livres for nave roof	Kraus 1979 (25). Doquang (155)	
		Philip Augustus Donates money for altars	Tallon/Sandron (22)	
		Eudes or Maurice de Sully donate money for roof	Aubert 1909 (33)	Guérard, IV, 145-46
1206		Queen Adele, mother of Phillip-Augustus, gave 20 marks of gold for work on the cathedral at her death	Aubert 1909 (34)	Guérard, IV, 79
ca. 1208	Transept completed		Tallon/Sandron (56). Erlande-Brandenberg (65, 87-89). Aubert 1909 (61).	
	Nave supports built on south before North and East to West		Bruzelius (562)	Column bases and plinth design images (found on Bruzelius 548)
	West facade under construction before Nave completed		Bruzelius (562)	Stylistic relation to eastern bays of nave and seams in masonry
	Destruction of houses of l'Hotel-Dieu		Mortet, 1888 (46). Aubert 1909 (34). Bruzelius (562)	
	Bishop Eudes de Sully buried under the keystone of the		Tallon/Sandron (48)	

	liturgical choir in bronze effigy			
1217		Agnès, first wife of Garin de Moncel, founded chaplaincy at Altar of Ste-Catherine	Kraus 1979 (217)	Guérard, I (400)
ca. 1218	Eastern bays of nave vaulted		Bruzelius (564)	
1218	(Roof) Fire		Chalus (scientifiquesnotre-dame .org)	
		Gift from Louis VIII and Blanche of Castille of chaplaincy of altar on south side	Kraus 1979 (215, n1). Aubert, 1920 (139, no 1)	
1219-1232	5 Taille, or taxes, imposed		Kraus 1979 (26)	
ca. 1220	Nave Completed, West facade under construction		Tallon/Sandron (68)	
	Towers constructed south to north		Bruzelius (565). Aubert (50)	Shafts supporting the wall-rib cut as detached, base and plinth profiles (Bruzelius, 563), portal details style analysis (Bruzelius, 566).
	Facade galleries constructed north to south		Bruzelius (565)	Windows, arcading (fig 30, Bruzelius 567)
1221		Raoul Poquet, founded chaplaincy dedicated to st Leonard	Kraus 1979 (217)	AN L. 414, no 16. Lebeuf based on Dubois , t. II, p 270/t. III, 570.
ca. 1225-1230	Fourth Master took over construction		Erlande-Brandenburg (95)	
ca. 1225	Renovations began		Tallon/Sandron (82). Erlande-Brandenburg (154).	
ca. 1228	Masons begin demolishing outer walls		Doquang (138 & 148). Aubert (149).	

	for chapels, expand buttresses in Choir		Tallon/Sandron (126) [Kimpel dates 1225: architecture of chapels namely windows, vaults, capitals, and entrances (39-40)]	
	New lancet windows		Doquang (138)	
	William of Aubergne new bishop	Donated biggest bell to the cathedral, north tower	Tallon/Sandron (17)	
1230	Possible completion of window renovations		Kraus 1979 (18)	
ca. 1235-40	Tower galleries completed		Bruzelius (566)	
1236		Purchase related to chapel of St. James	Doquang (144). Aubert, 1920 (138-39)	
1237		Emeline de Chaumont founded first chaplaincy at chapel of Ste. Anne	Kraus 1979 (217)	Parvum Pastorale, AN LL 270, no 222.
ca. 1240-5	Towers complete and decor of western facade mostly complete		Bruzelius (566)	
	Jean de Chelles, Transept architect (North Renovations)		Bruzelius (566). Tallon/Sandron (135)	
1241		Establishment of chapel of St. Michael	Doquang (144). Aubert 1909 (140)	AN S 88 A, no. 17.
1243		Marie dite Allemande founded chaplaincy at the episcopal palace	Kraus (217)	Guérard, 1, 152.
1244		Chantry at altar of St. Michael	Doquang (144). Aubert 1909 (140, no. 2)	An L 474, no. 192.
1246		Aléaume Hécelin founded chaplaincy at Chapel of St-Augutin	Kraus 1979 (217)	AN S 92.
1252		Donation to altar of St. Thomas from Herve Breton (Canon of Reims and then of Paris).	Doquang (144). Aubert 1909 (140)	AN L 474, no. 245
		Donation to chapel of SS George and Blaise from	Doquang (144). Aubert 1909 (140, no. 5)	AN S 93, no. 22. AN L 474, no. 41.

		Archdeacon Thomas le Noir of Bayeux.		BnF MS lat. 18361, fol. 185v. Guérard, IV (159).
		Donation to altar of SS Bartholomew and Vincent from Blanche of Castile.	Doquang (144). Kraus 1969 (128)	
1255		Odeline Coquilliere founded a chaplaincy at Chapel of St-Eustache	Kraus 1979 (217). Doquang (147)	AN S 87, nos 38, 39, 41. AN LL 7-8, no 95.
		Sancelina Hermande founded two chaplaincies at Chapel of St-Michel	Kraus 1979 (217)	AN L 76 Magnus Pastorale, Liber 20, no 92.
		Adam Bigue founds a chaplaincy dedicated to St-Julien and Ste-Marie-l'égyptienne	Kraus 1979 (217). Doquang (144)	AN LL 7-8, Magnum Chartularium, fol. xlvii r.
1257	Pierre de Montrueil took over, architect of South Side of Transept			
Mid-13th cent-ury	Transept arms expanded one bay, new facade		Aubert 1909 (151--5). Erlande-Brandenburg (150, 155-75). Branner (76-79 & 101-3).	Inscription in south portal, Pierre de Montreuil carved in homage to Jean de Chelles (d. 1257) (Tallon/Sandron 135).
1260		Raymond de Clermont gives more than 1000 pounds, some of it used to remake the chasse of St. Marcel (Tallon, 21)	Tallon/Sandron (21)	
1263		Agnès Le Roux, founded chaplaincy for St Louis (paid an amortization to St Louis on a rent of 15 livres)	Kraus 1979 (217)	AN S 80, no 9
1265		Benoit de St-Victor founded second chaplaincy at Chapel of Ste-Anne	Kraus 1979 (217). Aubert 1909 (140)	

1266		Hugues de Vitry founded chantry at Chapel of St. Lawrence	Doquang (144). Aubert 1909 (140-41)	BnF, MS lat. 18361, fols 185-186. AN L 474, no. 157.
1267 or 1270		Marguerite Houdeard founded chaplaincy at Chapel of Sts-Piere-et-Paul	Kraus 1979 (217)	AN S 90b, nos 66 and 68
ca. 1268		Girard of Courlandon constructs chapel of Saint Nicaise	Tallon/Sandron (21)	
1268		Josse, Sergent of the bishop, founded a 'second' chaplaincy at altar of St-Eustache	Kraus 1979 (217)	AN L 474 and L. 535, no 14
1270		Canon Jean de paris left money "for work on the transepts recently begun"	Kraus 1979 (25)	
1275		Marie, widow of Baudouin Marechal	Kraus 1979 (218)	AN LL 76, Liber 20, no 223
		Jean Sarrazin founds chaplaincy at Ste-Agnès chapel	Kraus 1979 (217)	AN LL 246
1278		Pierre Apothicaire founded chaplaincy at chapel of St-Gérard	Kraus 1979 (218)	AN S 93, nos 7 and 55
1283		Eudes de Saint-Denis founds chantry at altar of St. Nicholas	Doquang (144). Kraus 1969 (129).	
1285		Henri Tuebeuf (canon and subdeacon at Notre-Dame) establishes chantry in chapel of St. Leonard	Doquang (144). Kraus 1969 (129).	
ca. 1285	Completion of Nave chapels		Doquang (144)	
ca. 1296	Construction of hemicycle chapels began	Bishop Simon Matifas de Bucy donated 600 livres parisis and 100 Livres tournois for SS. Marcel, Rigobert, and Nicaise	Doquang (150). Tallon/Sandron (127)	BnF, MS lat. 5185 CC fol 224. Guérard, 4, (92)

1296		Gilles Arrode founds chaplaincy at chapel of St-Rigobert	Kraus 1979 (218). Aubert 1909 (13)	AN S 92
1299		Galerand Le Breton founds chaplaincy at Chapel of St-Louis	Kraus 1979 (218) Aubert 1909 (13).	AN L 535, no 19. AN S 87, no 51. S 87, no 51 (dates foundation as March 1302)
1302		Etienne and Jeanne Haudri	Kraus 1979 (218)	AN LL 76, Liber 22, no 49
1304	Simon de Buci/Budy dies, donation, and is buried in the axial chapel		Tallon/Sandron (127)	
		Bishop Simon Matiffa de Buci leaves over 5,000 livres for creation of three axis chapels	Kraus 1979 (25)	
1313		Philippe le Pévrier founded chaplaincy for his father, Jean	Kraus 1979 (218)	AN LL 7-8, fol 261
1316	Eudes de Sens buried in chapel of SS Peter and Stephen		Tallon/Sandron (123-124)	
1318		Jacques Boucel founds chaplaincy at chapel of St-Pierre-Martyre	Kraus (218)	AN LL 7-8, fol 259v
ca. 1320	Completion of chapels		Doquang (137, 144, 154). Davis (58-72). Gaposchkin (39)	
1320	Archdeacon Girard de Courlandon buried in chapel of St. Nicaise		Aubert 1909 (146-7)	
ca. 1325-50	Altar work (remained same until 1699)		Tallon/Sandron (54)	
1326		Jean Haudri founded two chaplaincies	Kraus 1979 (218)	Guérard, III (228)
1328		Geoffrey de Plessis founded a chaplaincy at the Chapel of Sts-Martin-et-Anne	Kraus 1979 (218)	AN LL 247, Capellaniae.

1329		Pierre and Pernelle Mulet founded chaplaincies at St-Jean-Baptiste and ste-Mariemadeleine	Kraus 1979 (218)	AN S 88, no 99
1331		André Giffart founded chaplaincy at altar of Ste-Genevieve	Kraus 1979 (218)	Lebeuf, IV (438). AN L 535, no 30)
1332		Marie le Josequine, founded "chaplaincy in the church of Paris, in honour of the Virgin Mary and St Denis"	Kraus 1979 (218)	Viard I (1328-38)
1336		Dreue de la Charité, Philippe VI's clerk	Kraus 1979 (218)	Viard, I (1328-38)
1337		Amaury de Gray founded chaplaincy of Sts-Innocents at the Altar of Ste-Catherine	Kraus 1979 (218)	Poete, III. AN S 94b, no 31.
1339		Pierre Barrier	Kraus 1979 (218)	Viard, I, no 226
1340		Martin des Essars founded chaplaincy at Altar of St-Eutrope	Kraus 1979 (218)	Viard, I, no 229
1342		Jeane d'Avranches altar not named	Kraus 1979 (218)	Viard, I, no 294
1340s		Jean le Leu bequest of 13 livres of annual quitrents "to sing the Inviolate every day and at processions of the Assumption and the Nativity"	Kraus 1979 (218)	Viard, I, no 133
ca. 1350	Jubé constructed		Tallon/Sandron (132)	

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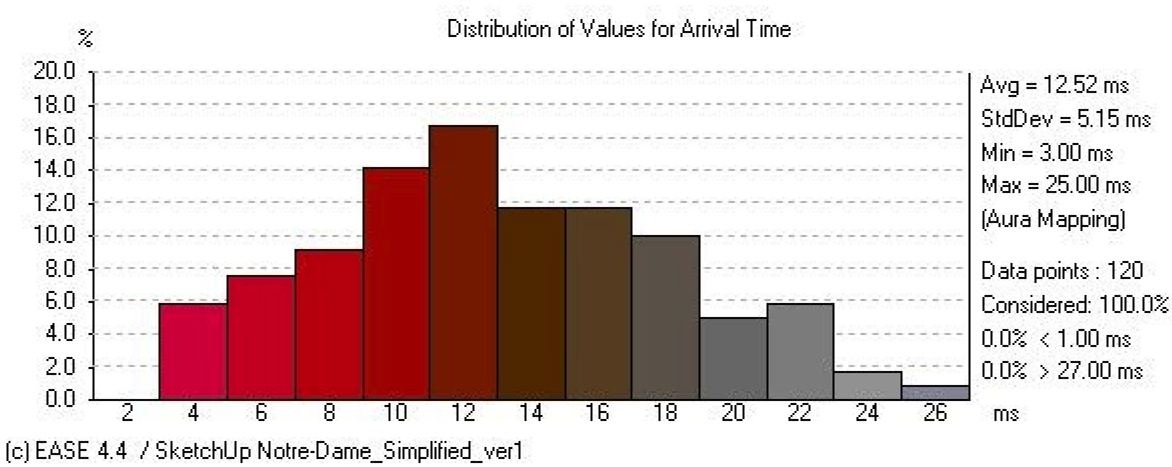
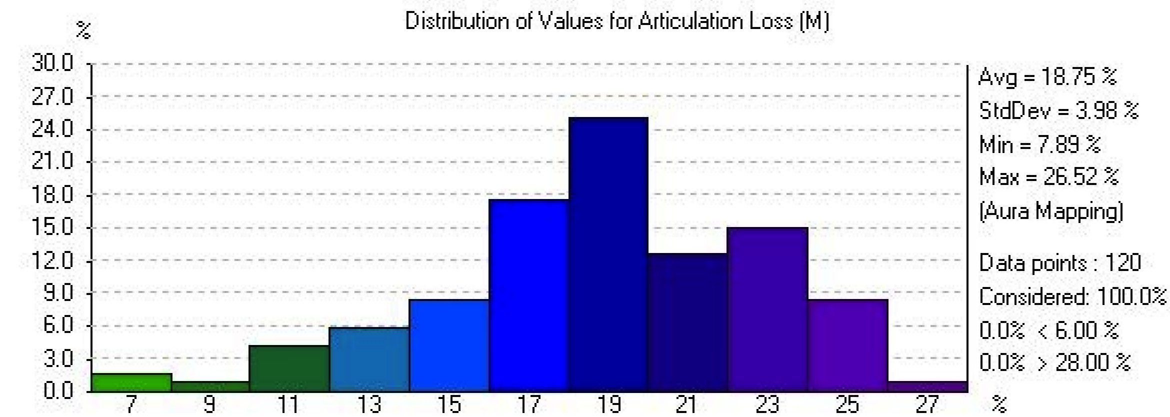
Appendix II

Chapter 3
Acoustic Results from all Simulations

The following graphs and tables were produced through EASE AFMG 4.4 in collaboration with Dawn Schwartz. They provide more details on the acoustic environment of the Notre-Dame choir space. The tables found in Chapter 3 are based on the graphs and tables below. They are organized by number of sound sources (single, two, and four) and then volume level ("normal" then "raised").

Single Normal Male Voice





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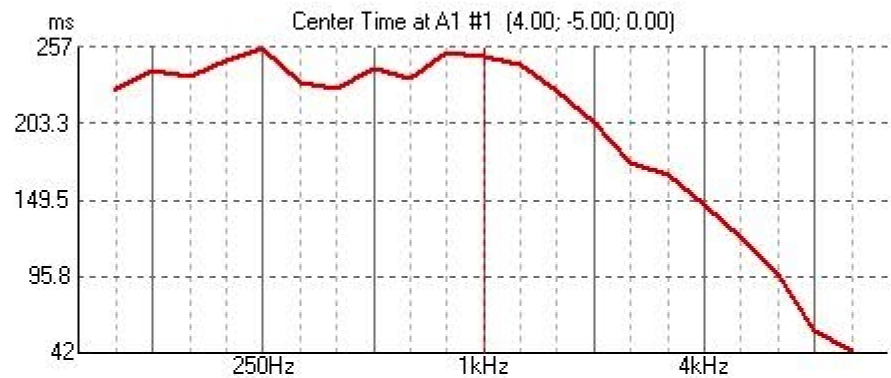

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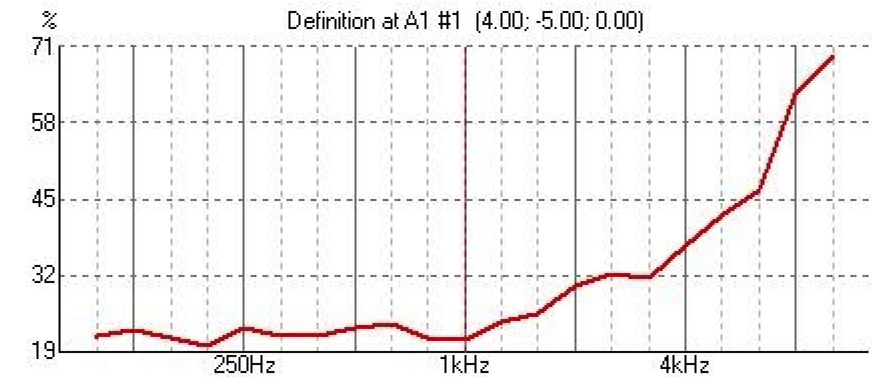

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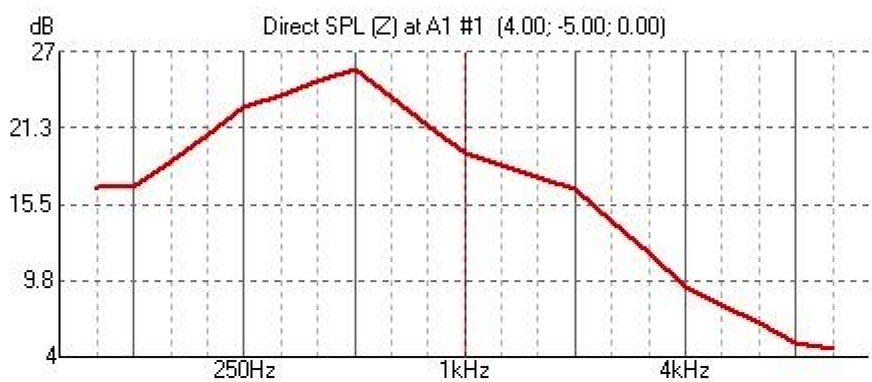

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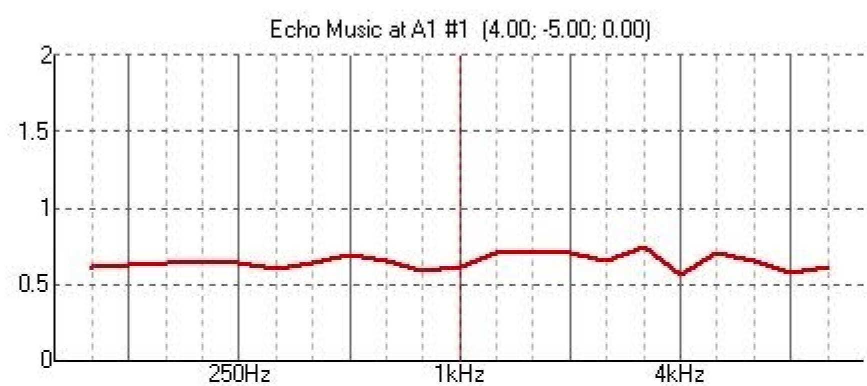

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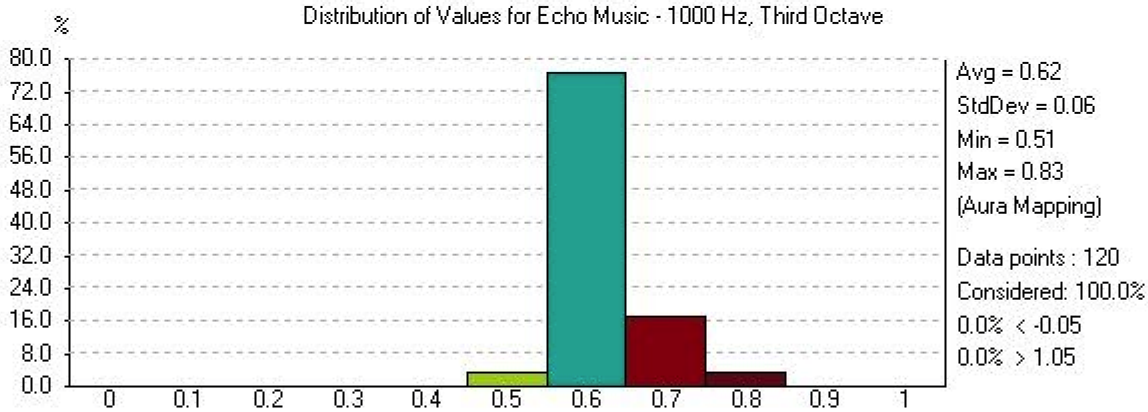

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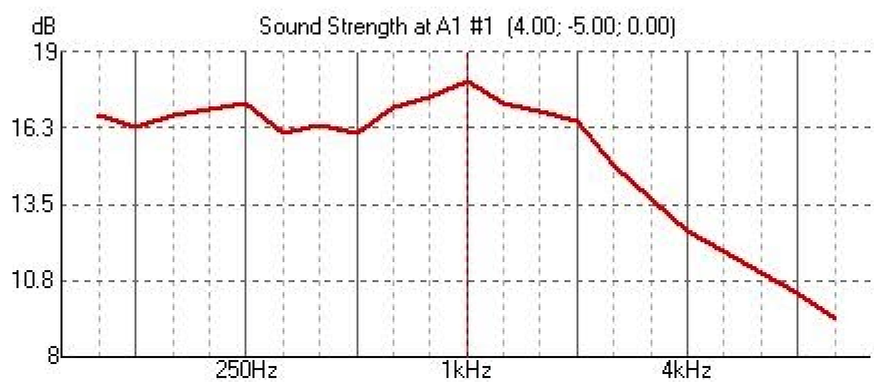

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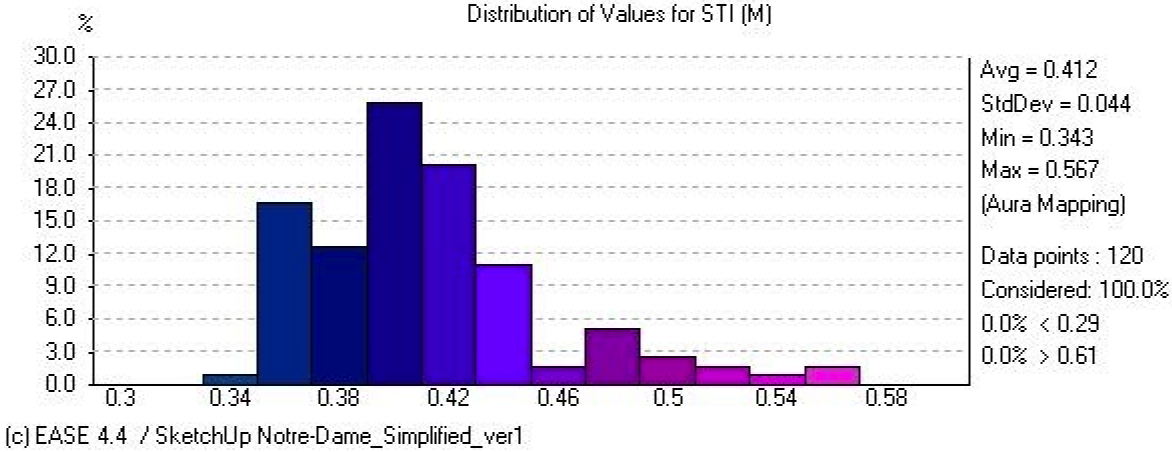
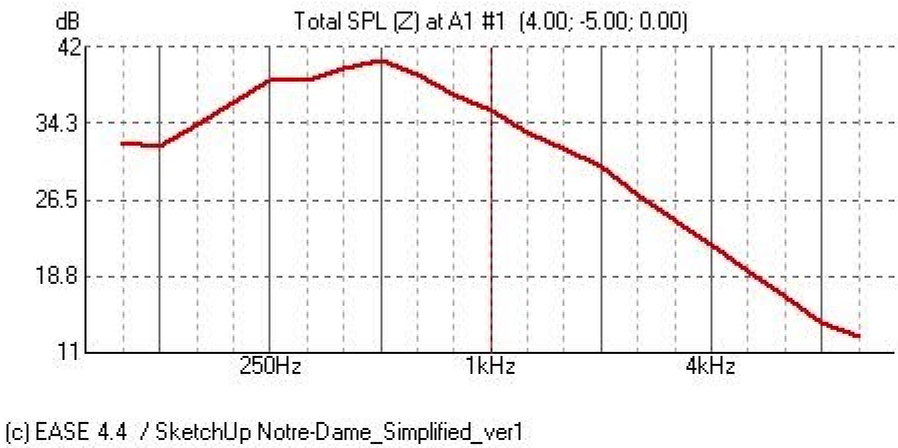
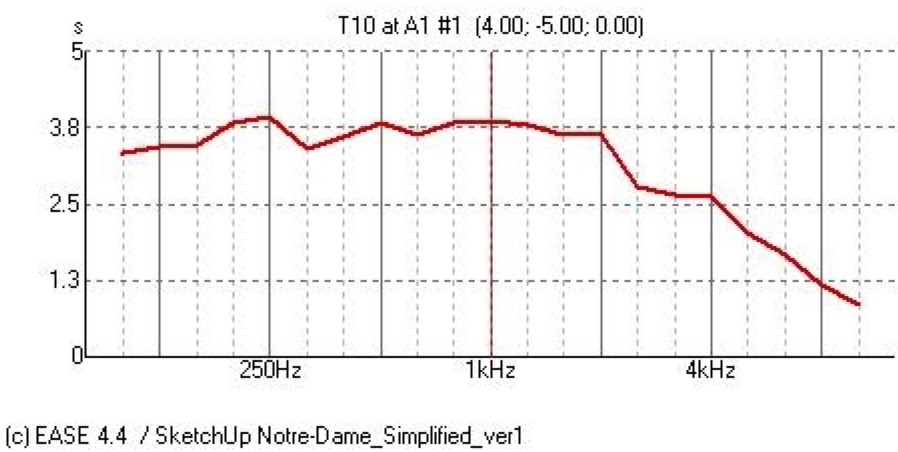
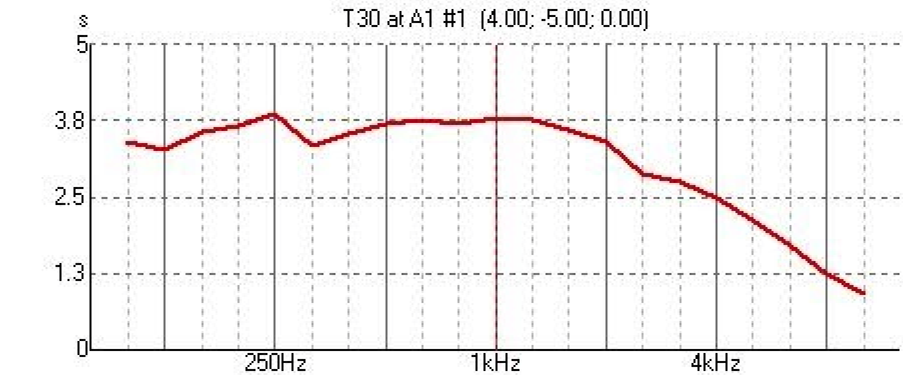

Distribution of Values for STI (M)
%
Avg = 0.412
StdDev = 0.044
Min = 0.343
Max = 0.567
(Aura Mapping)
Data points : 120
Considered: 100.0%
0.0% < 0.29
0.0% > 0.61
(c) EASE 4.4 / SketchUp Notre-Dame_Simplified_ver1

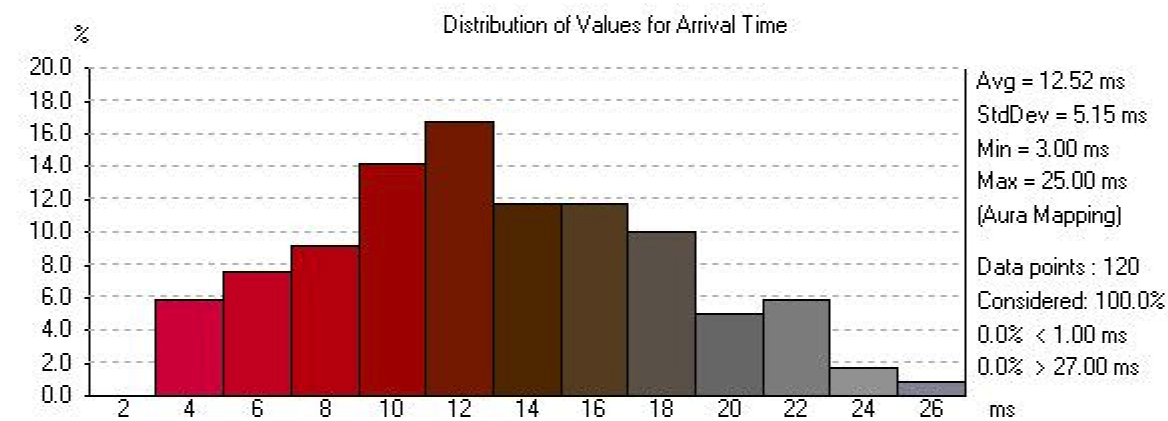

dB
Total SPL (Z) at A1 #1 (4.00; -5.00; 0.00)
250Hz
1kHz
4kHz
(c) EASE 4.4 / SketchUp Notre-Dame_Simplified_ver1


s
T10 at A1 #1 (4.00; -5.00; 0.00)
250Hz
1kHz
4kHz
(c) EASE 4.4 / SketchUp Notre-Dame_Simplified_ver1



(c) EASE 4.4 / SketchUp Notre-Dame_Simplified_ver1

Single Male Raised Voice



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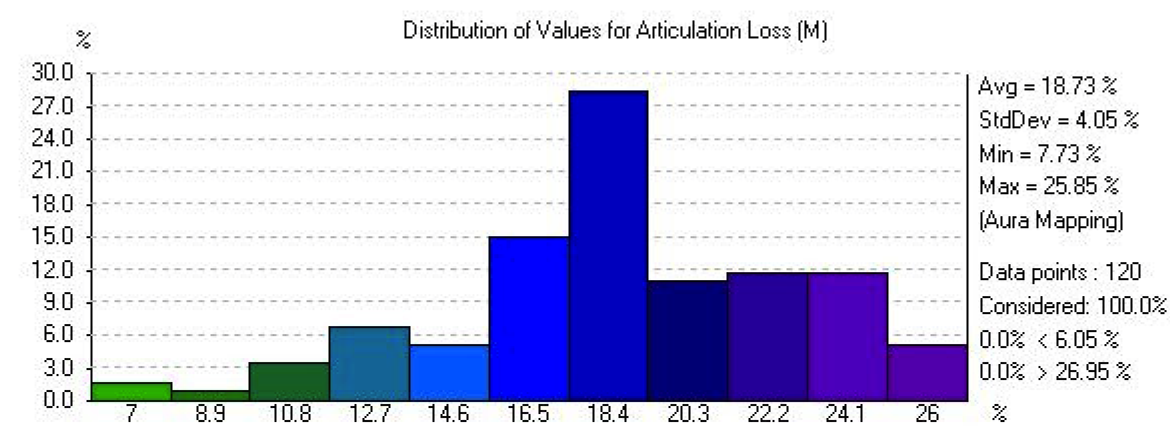

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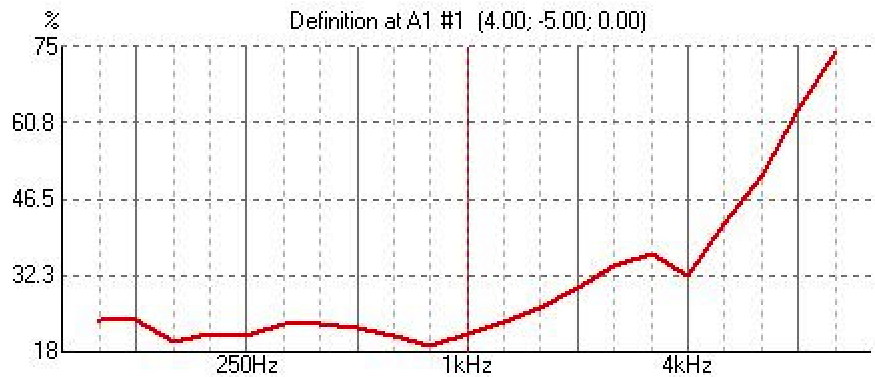

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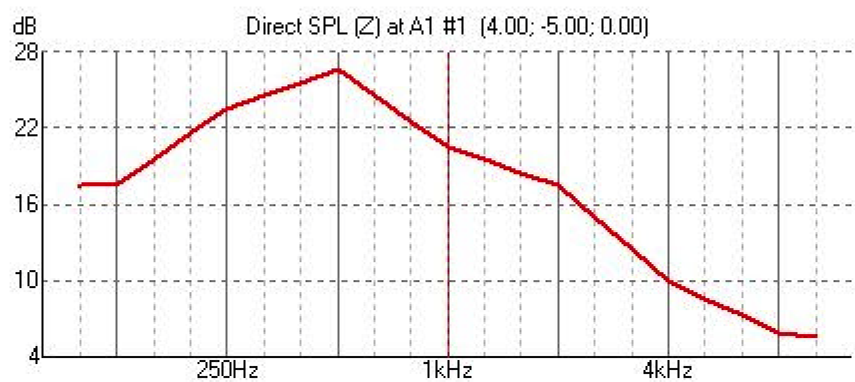

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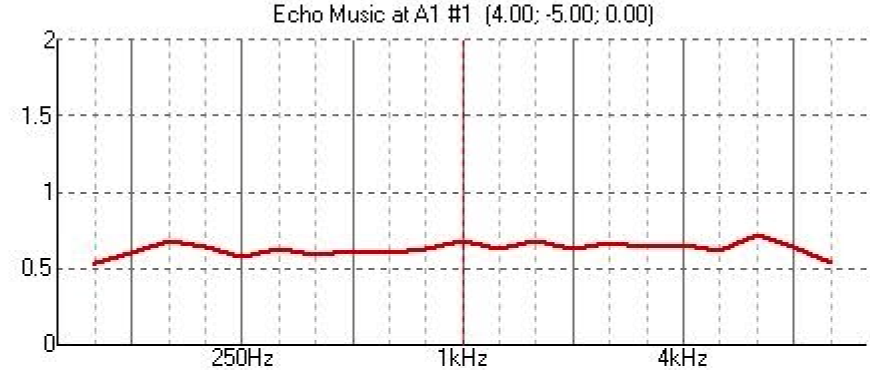

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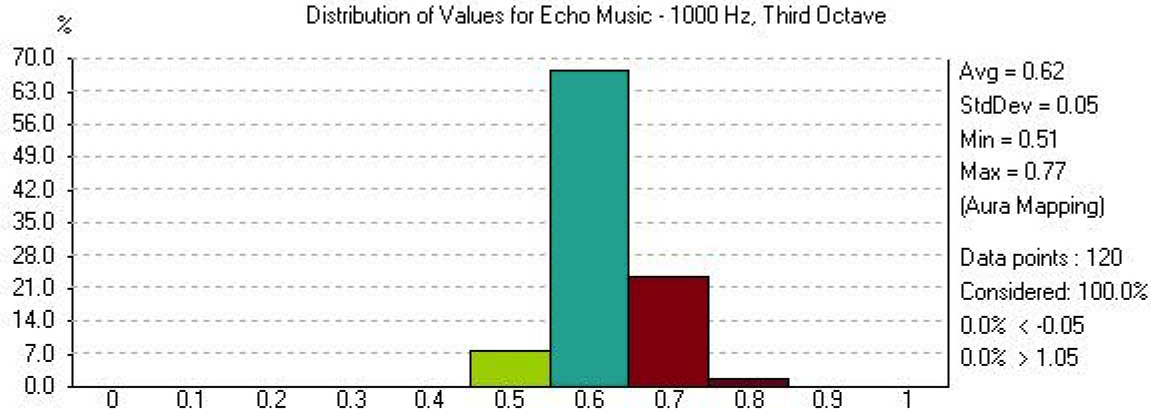

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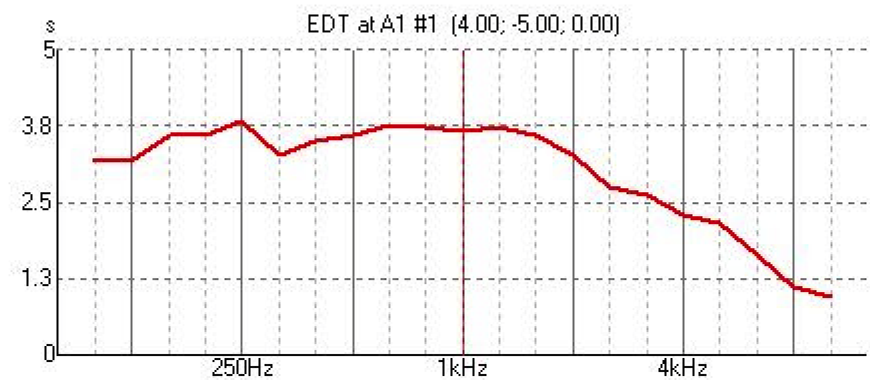

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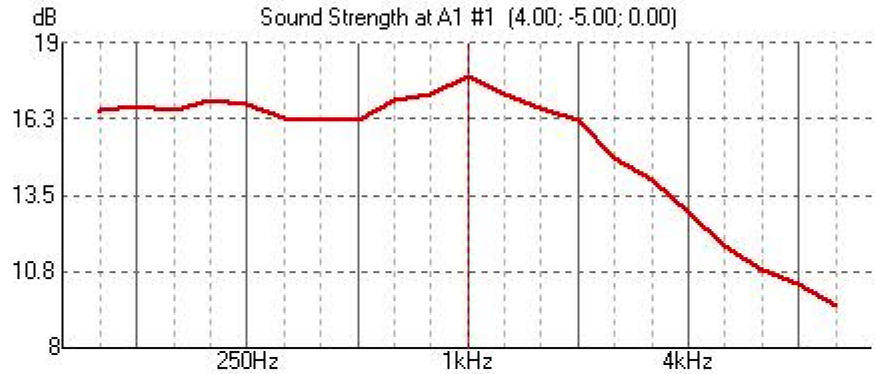

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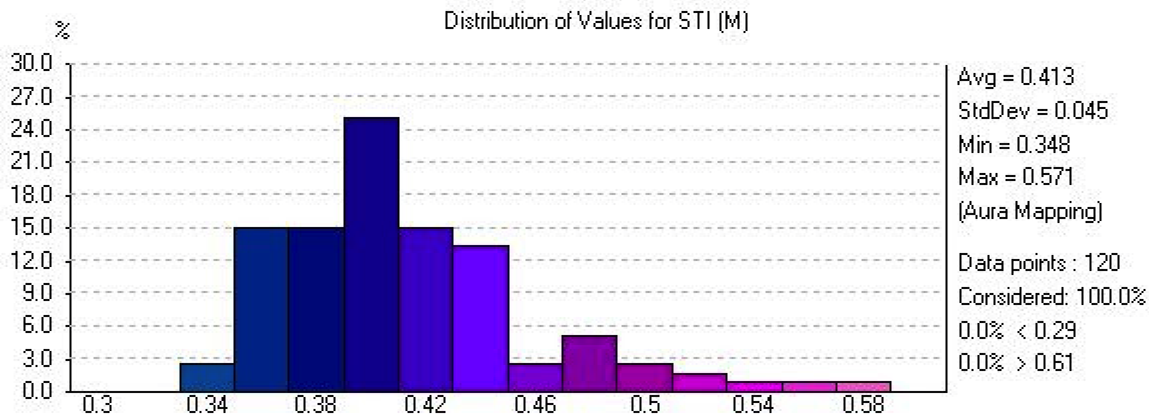

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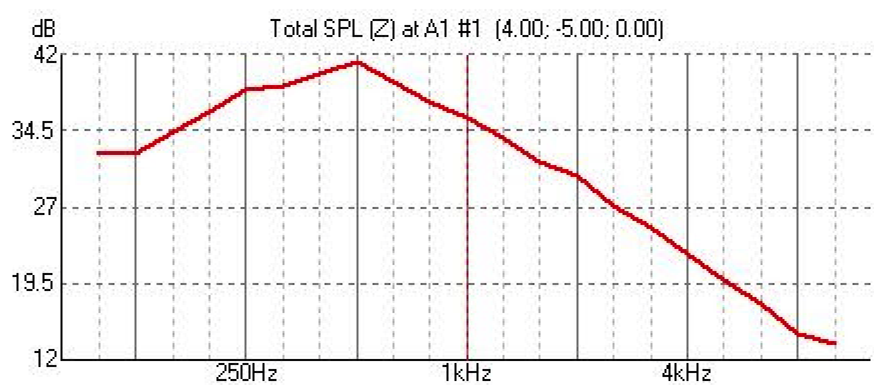

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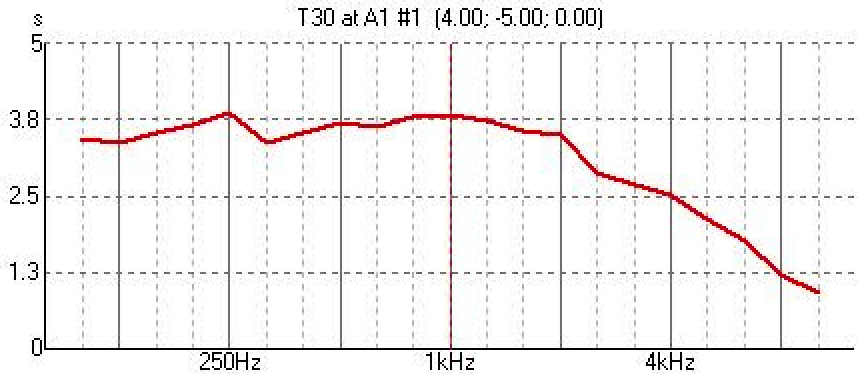

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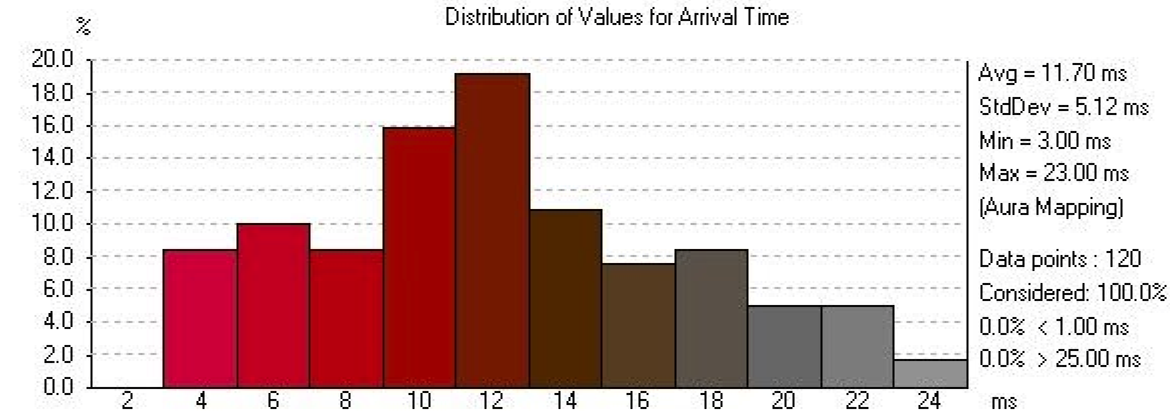
Two Male Normal Voices



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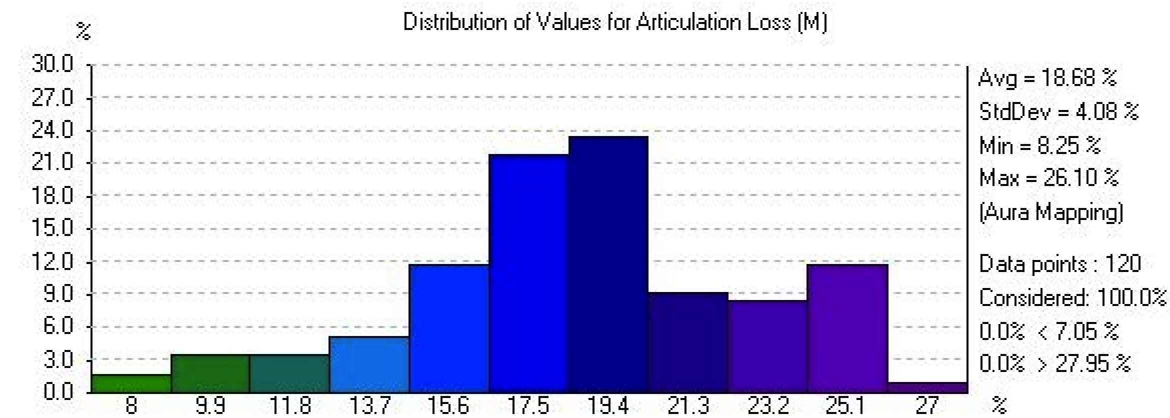

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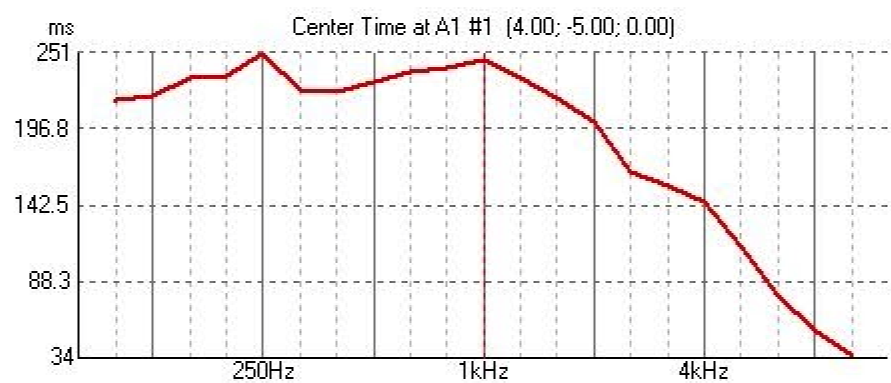

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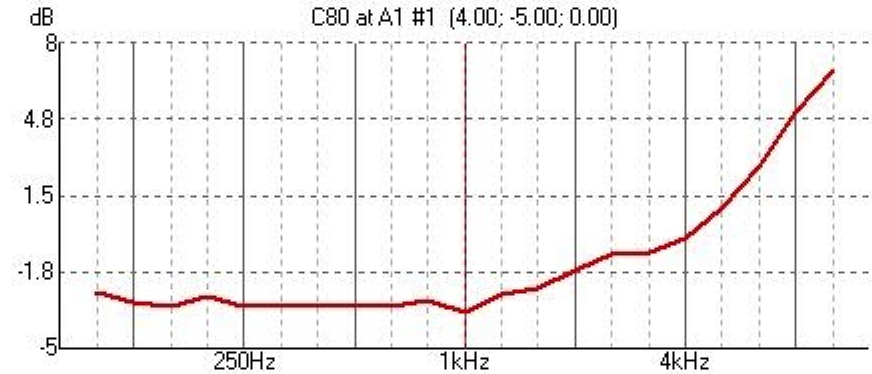

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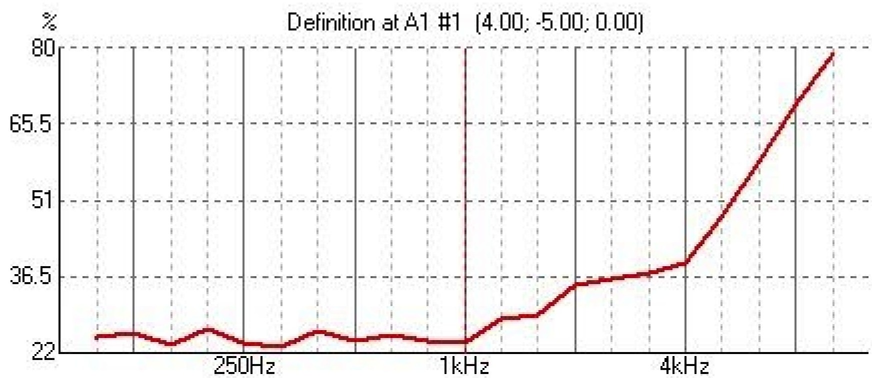

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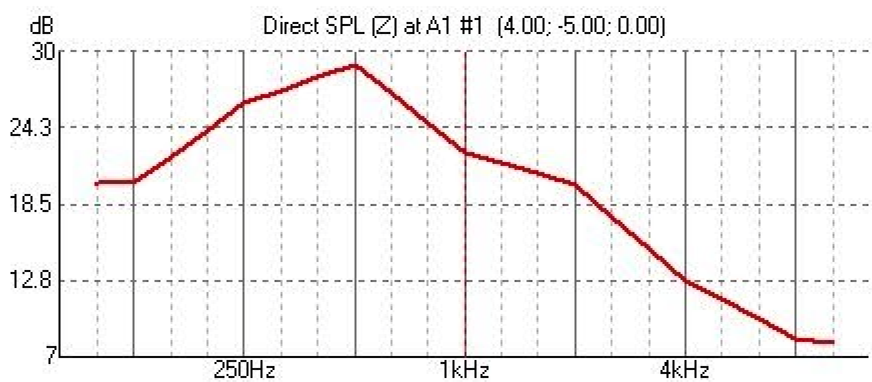

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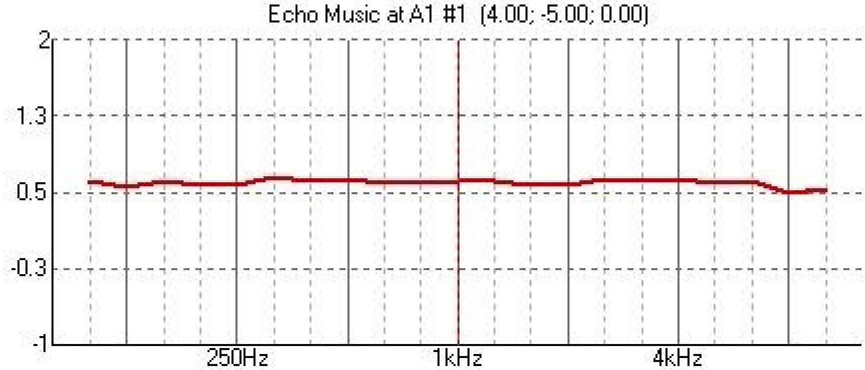

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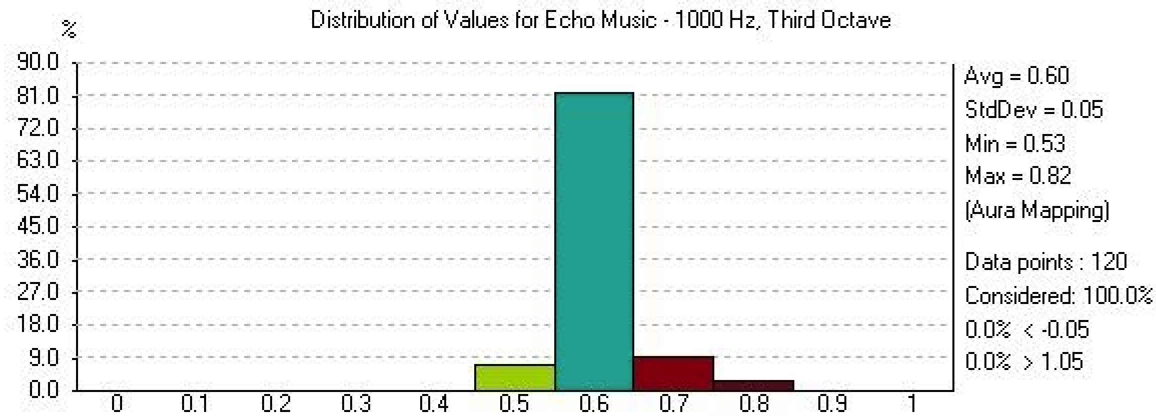

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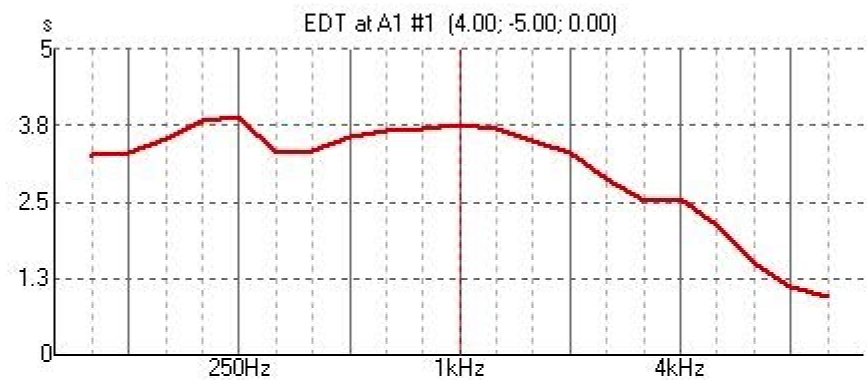

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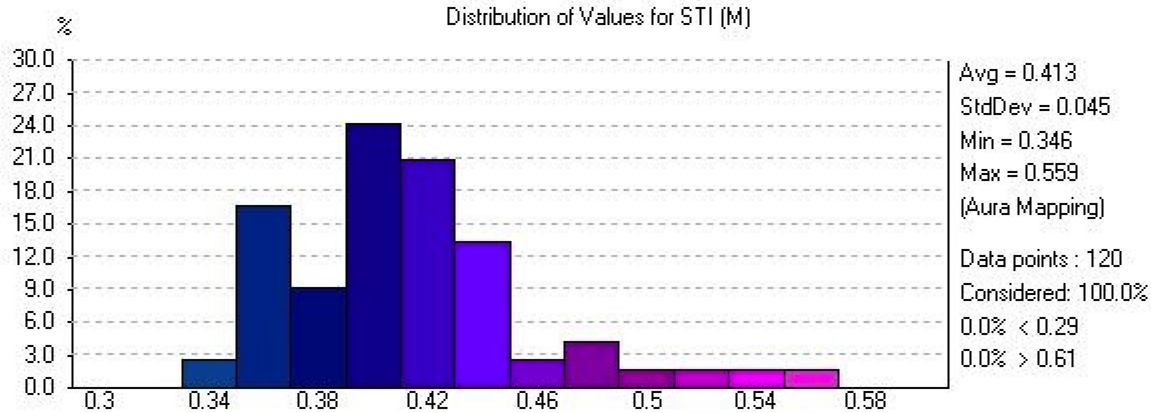

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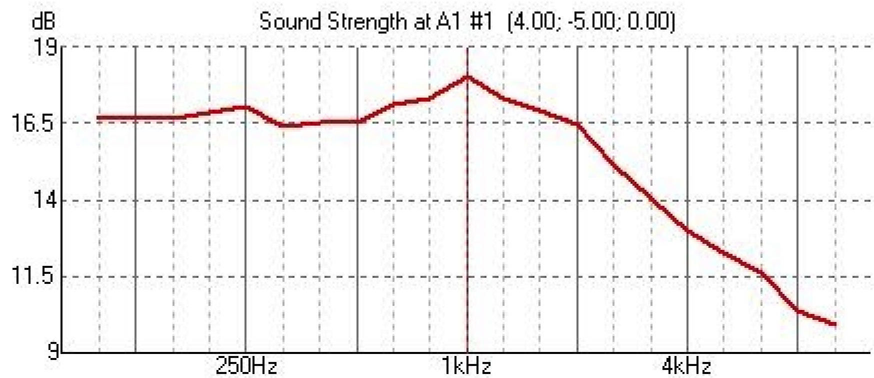

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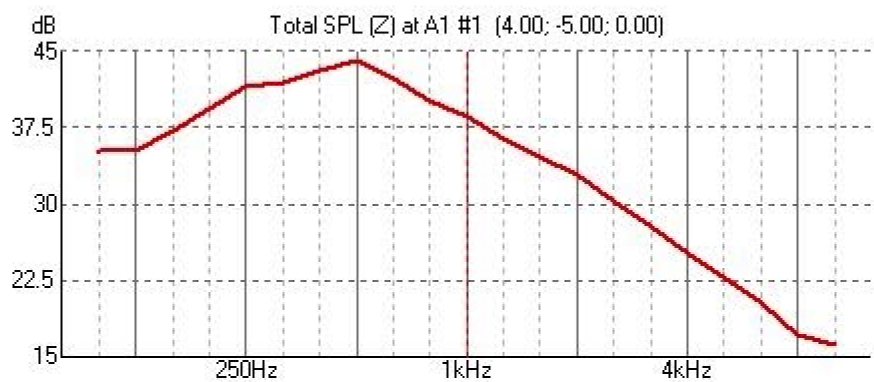

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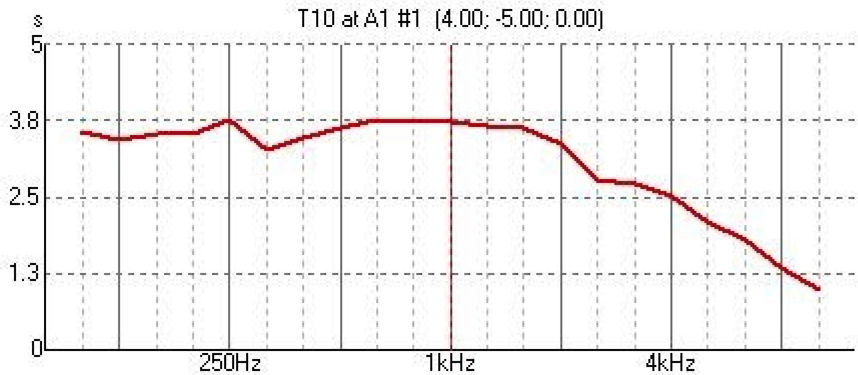

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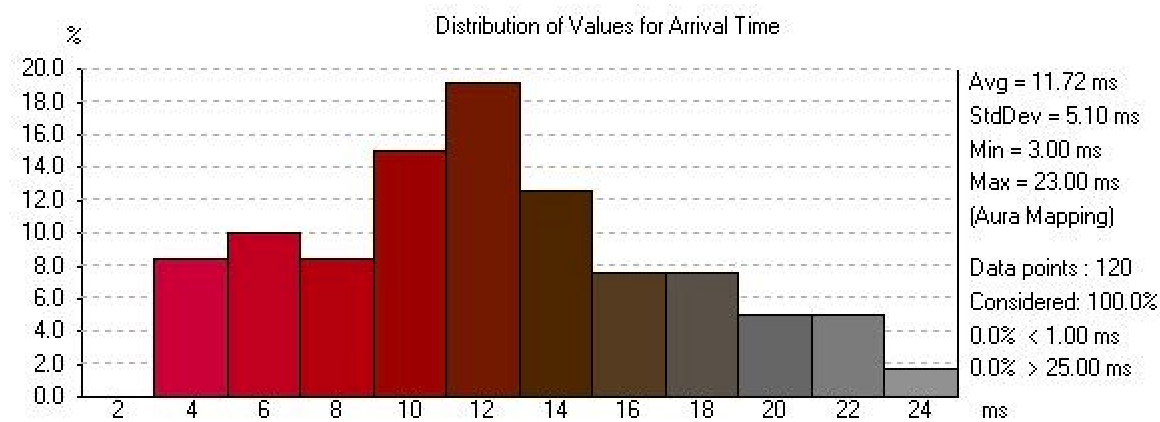

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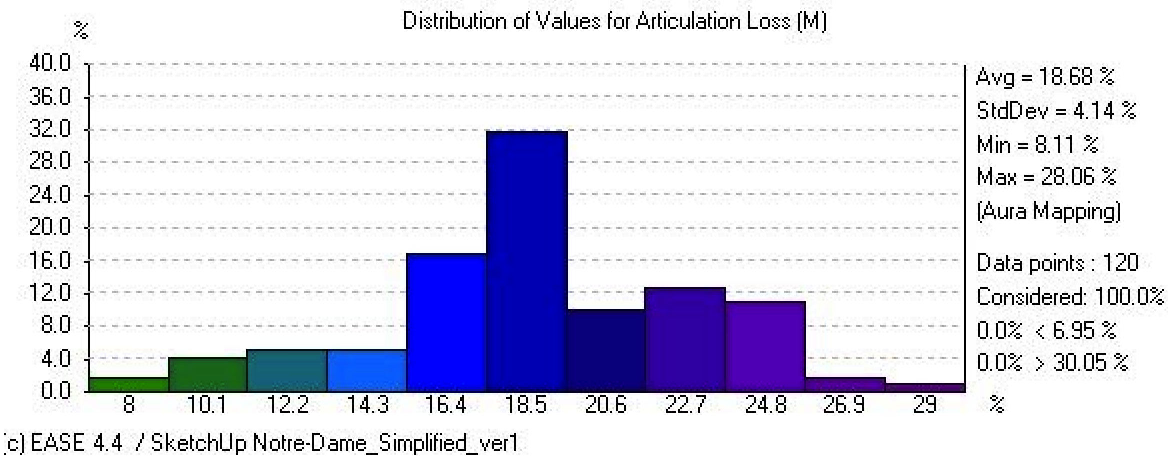

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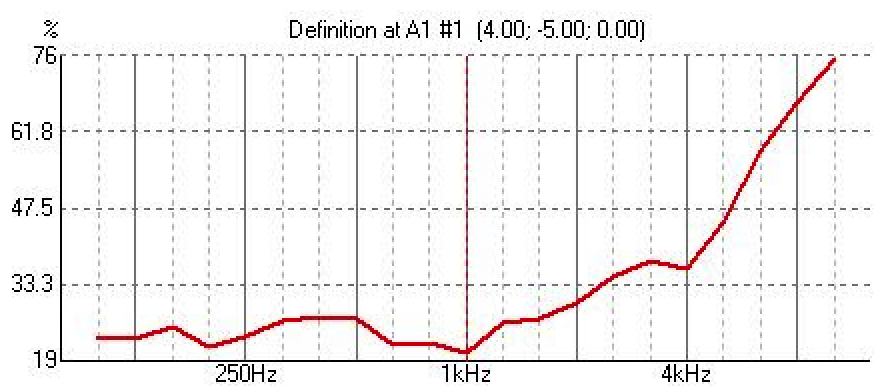

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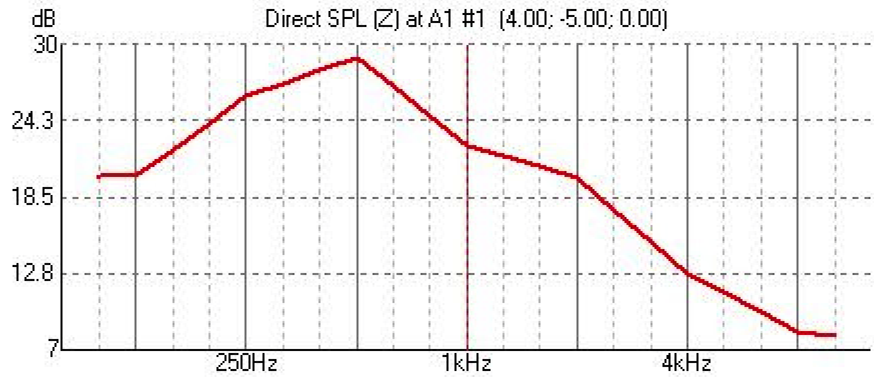

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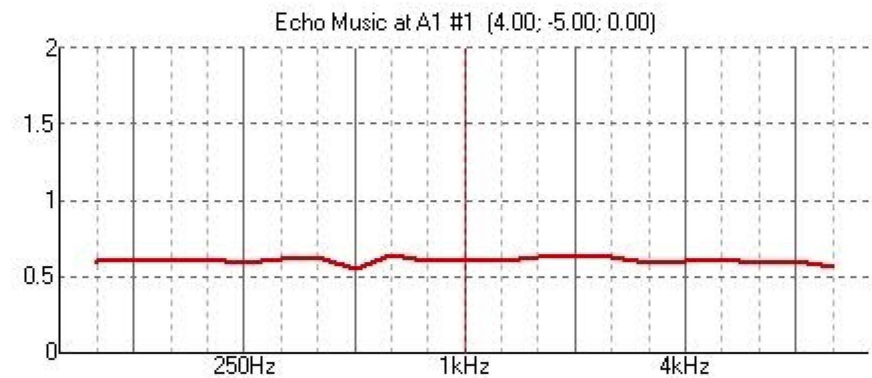

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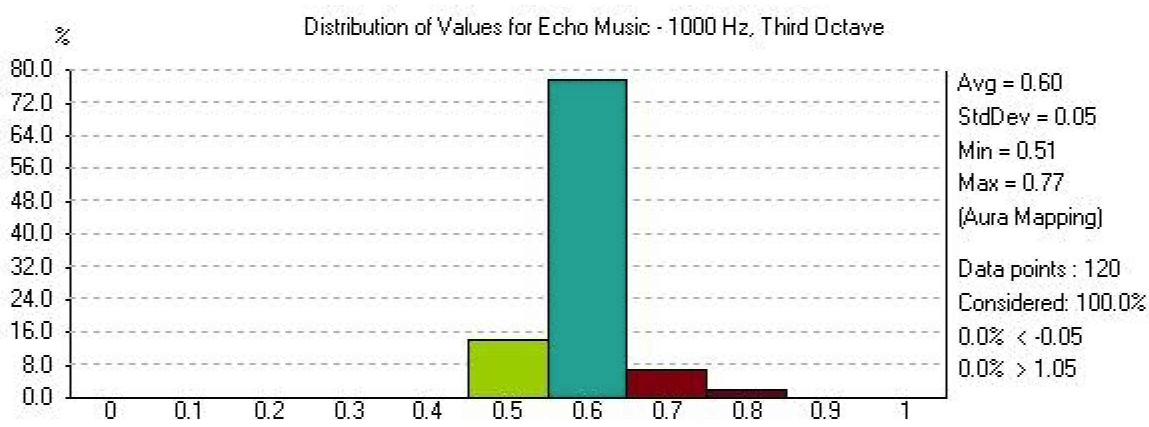

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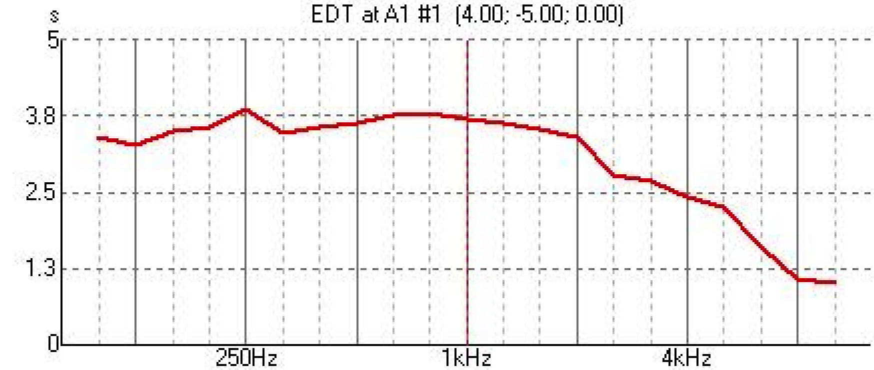

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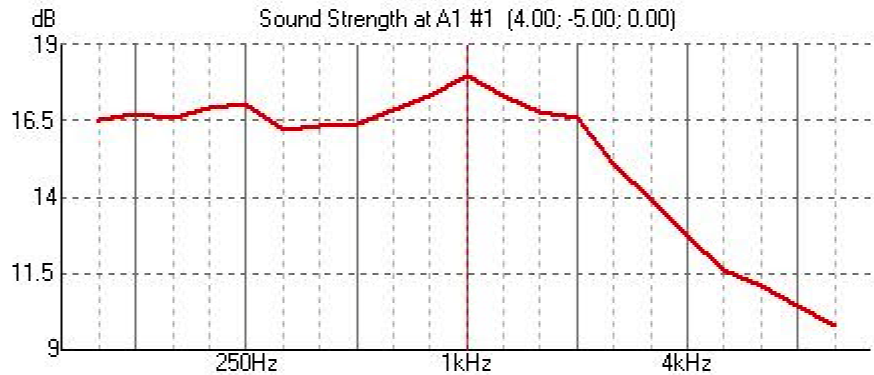

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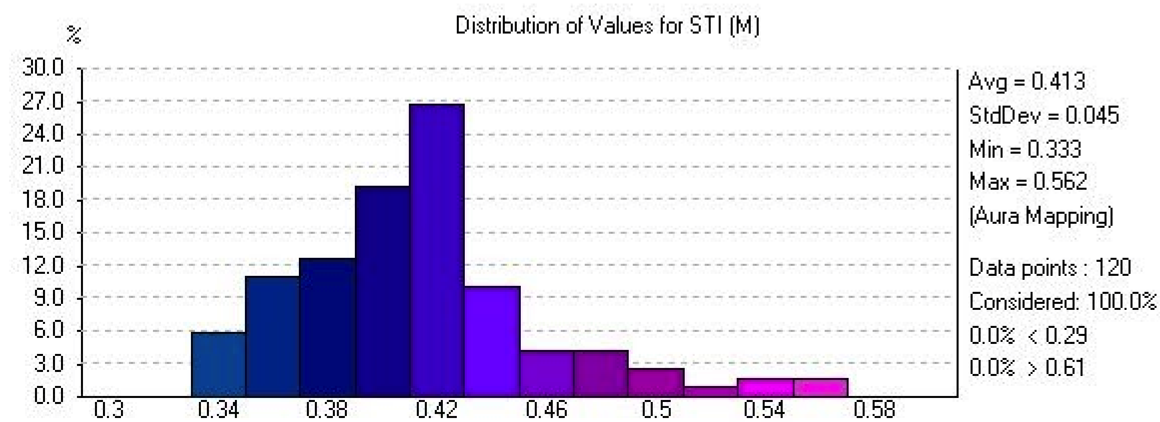

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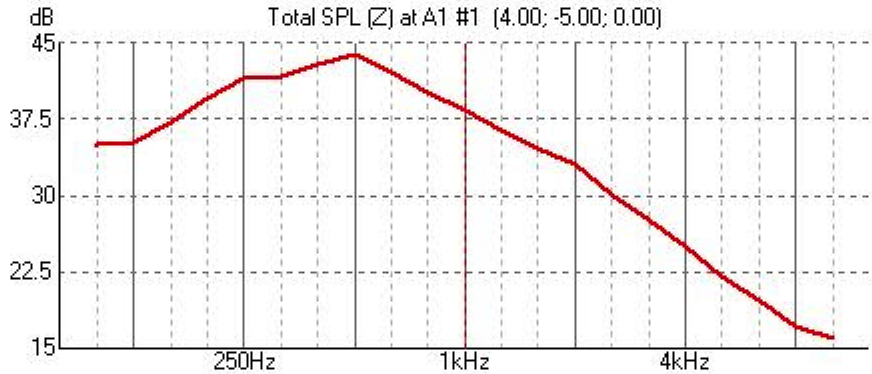

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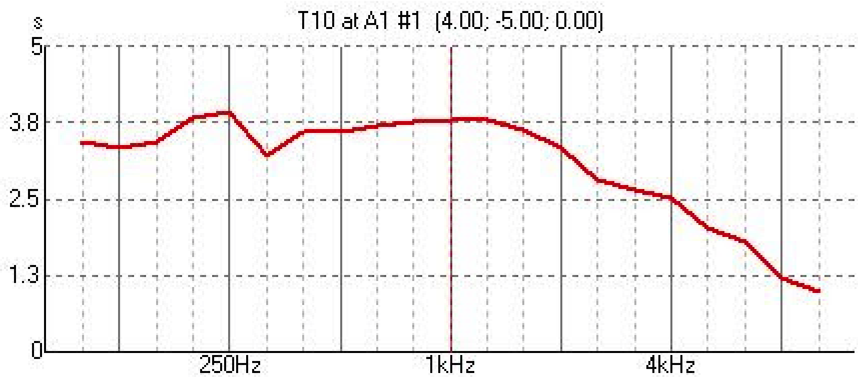

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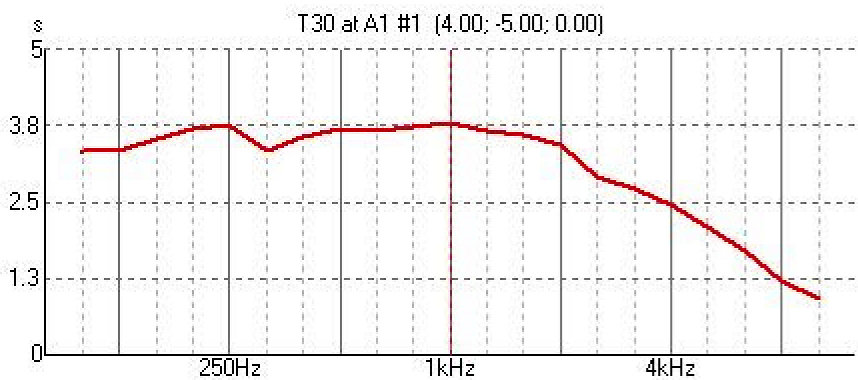

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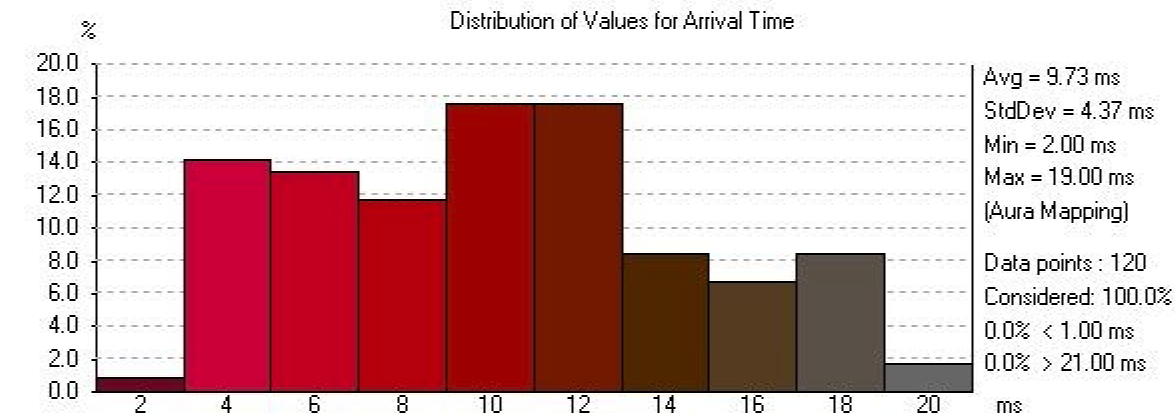
Four Male Normal Voices



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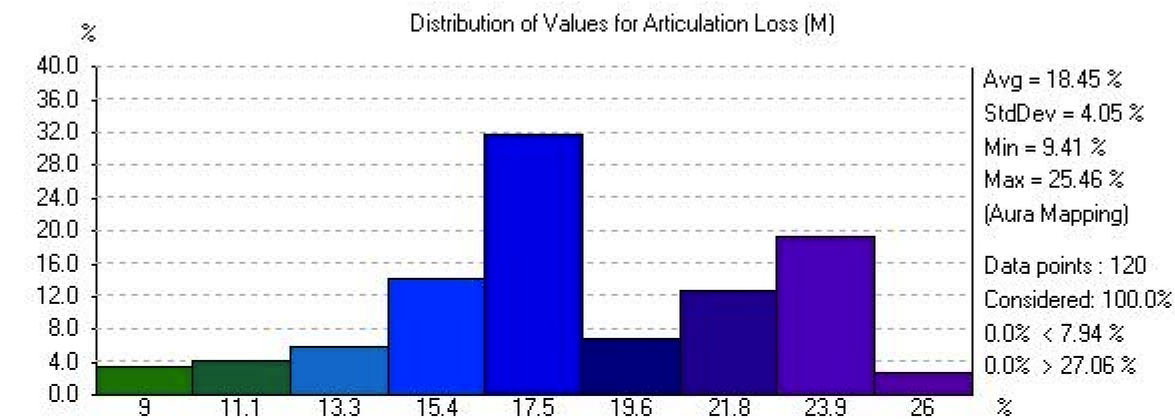

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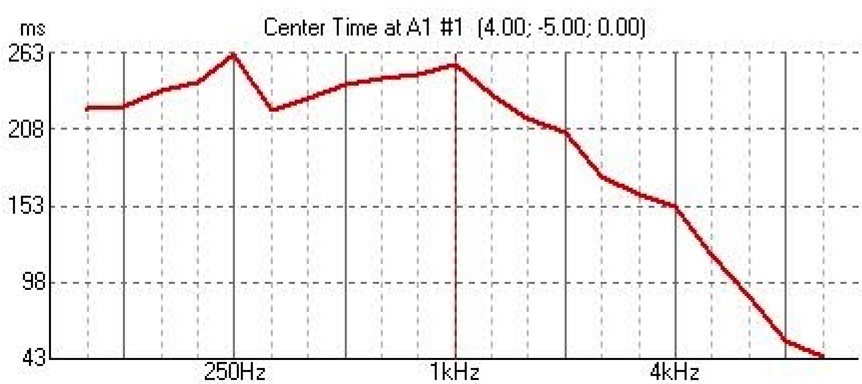

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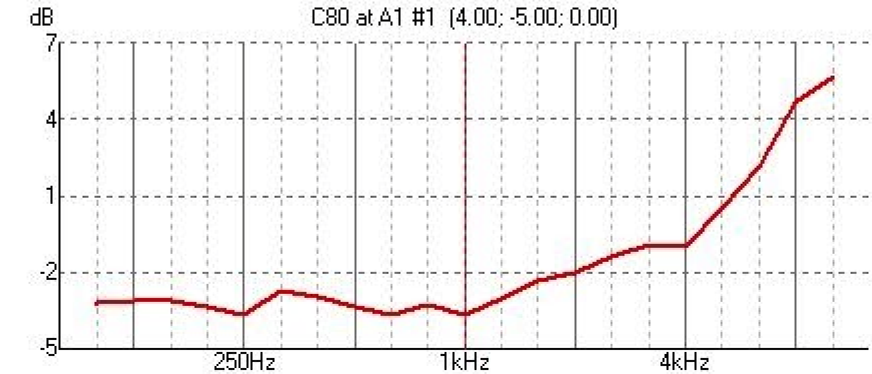

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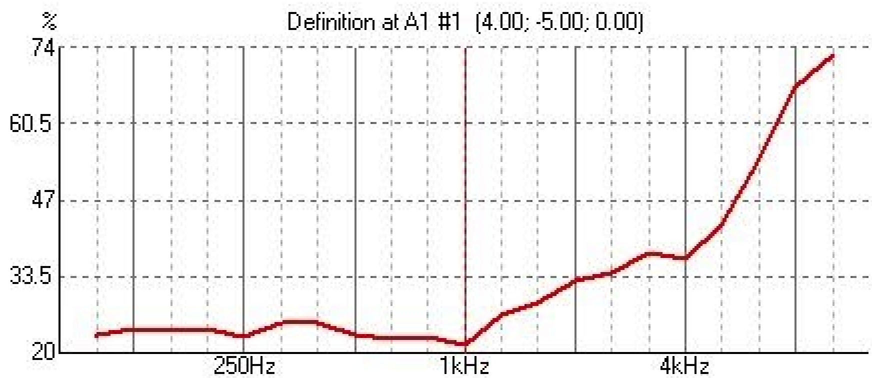

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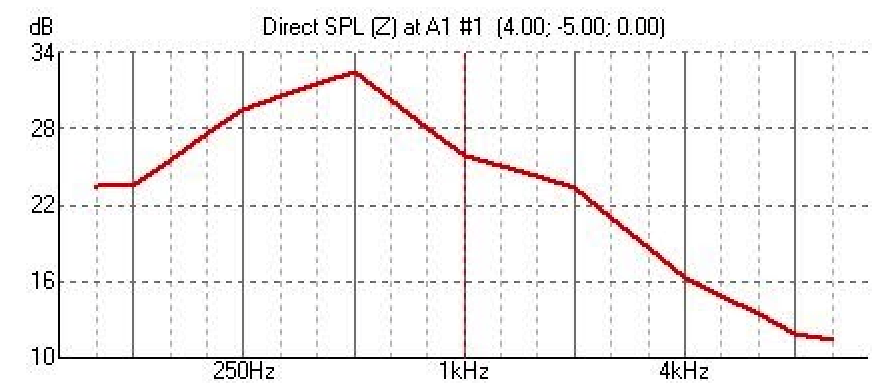

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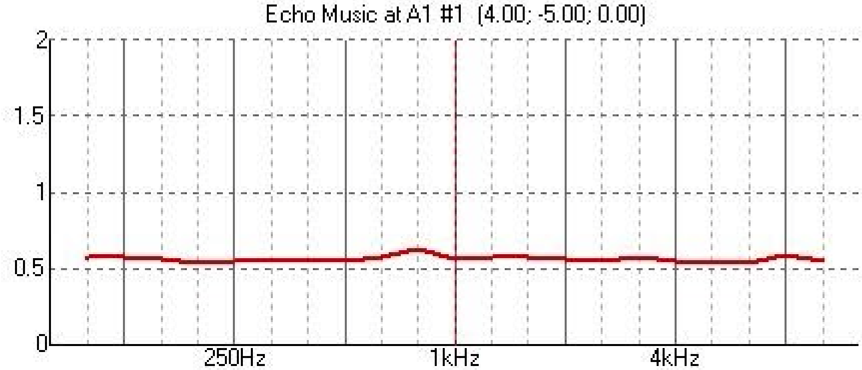

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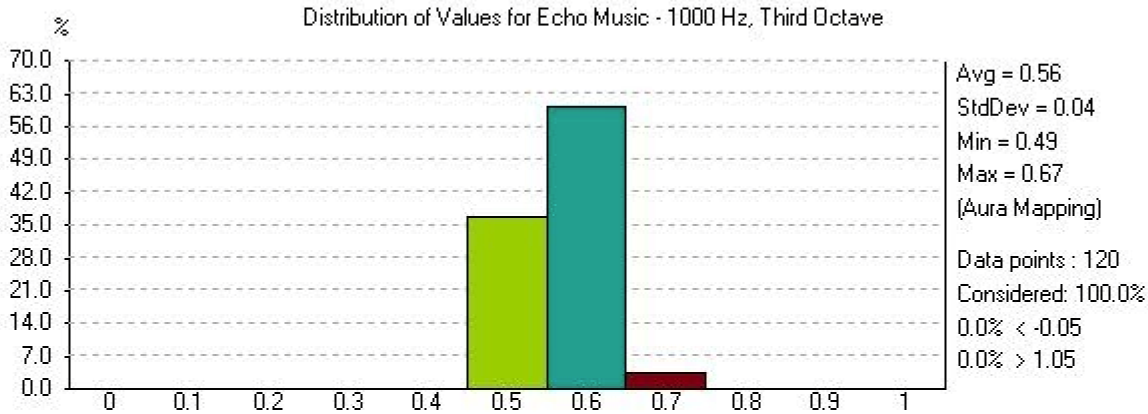

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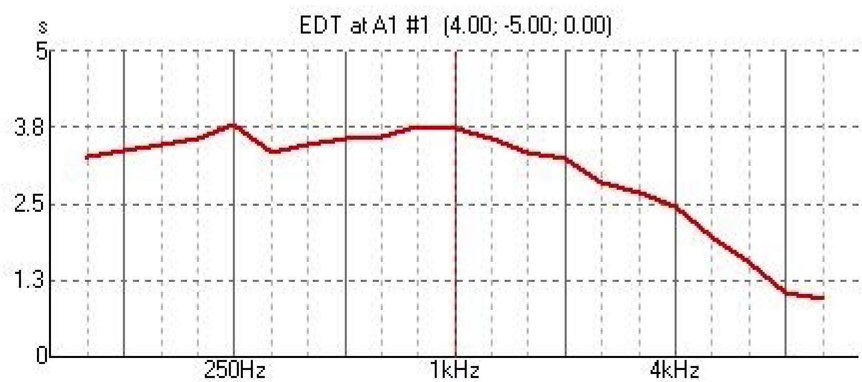

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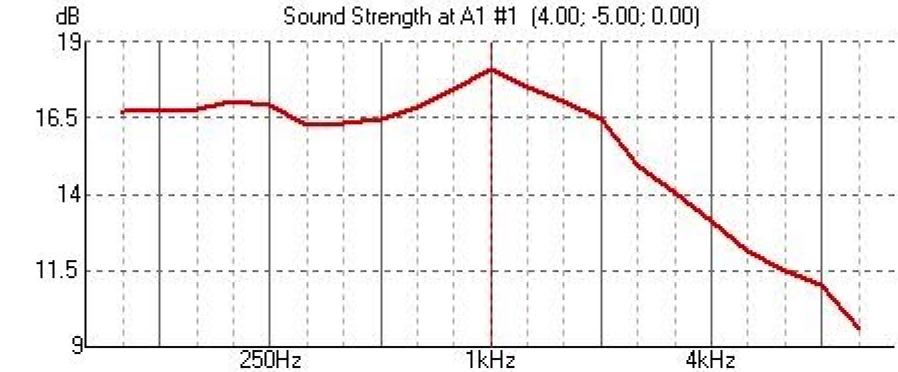

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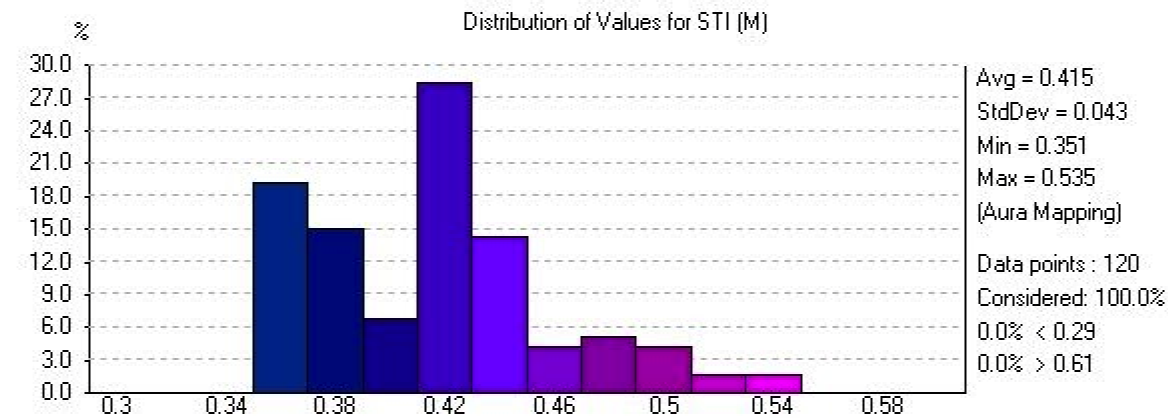

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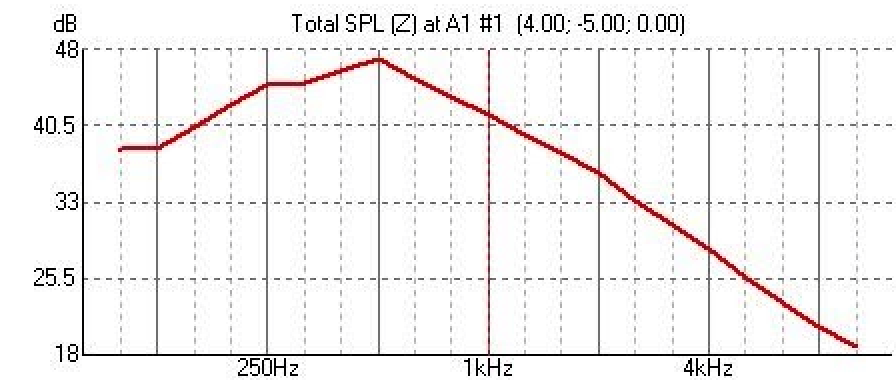

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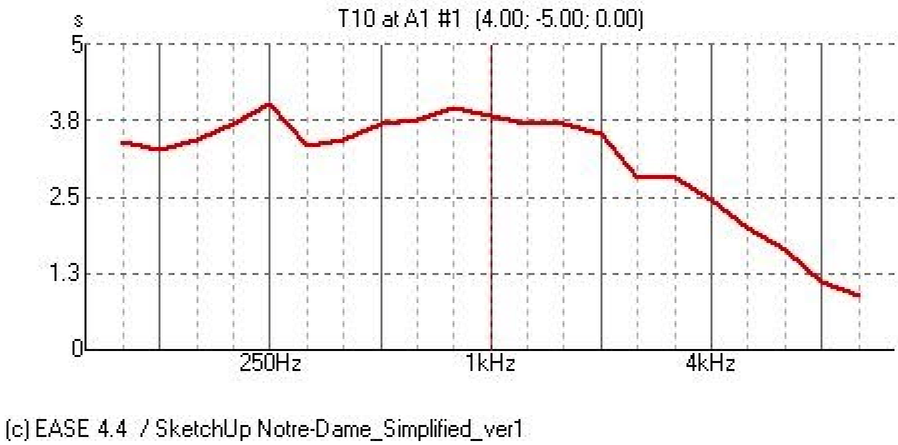

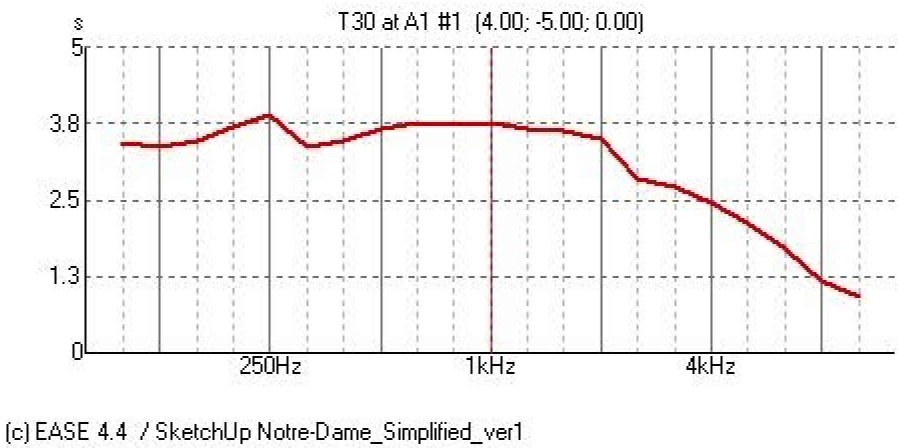

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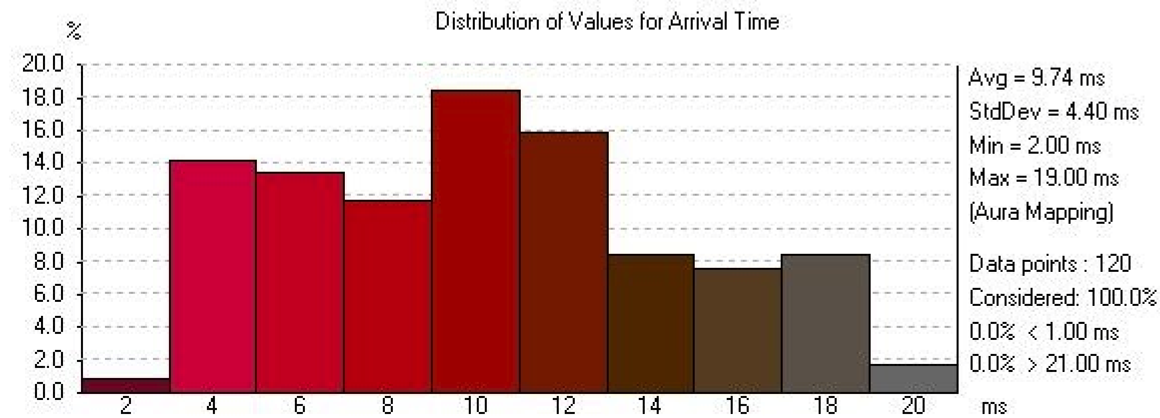

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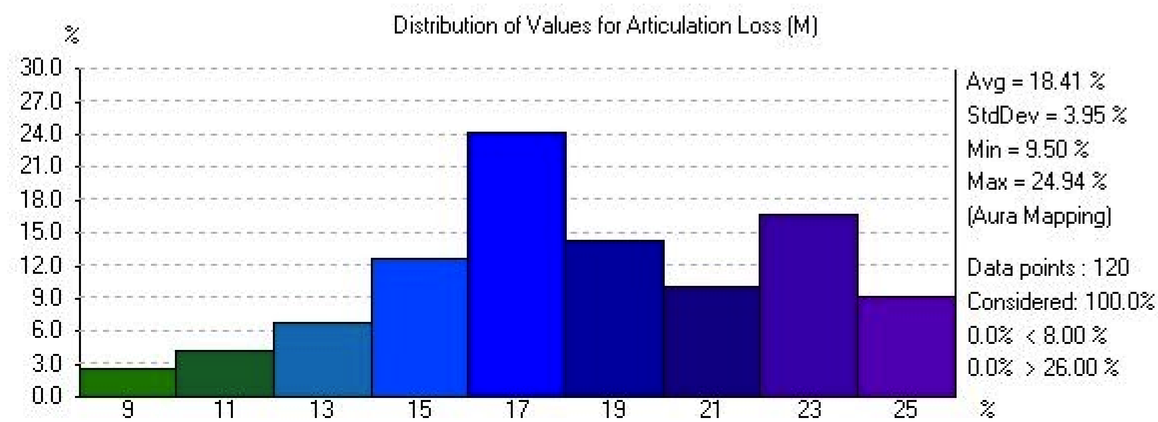

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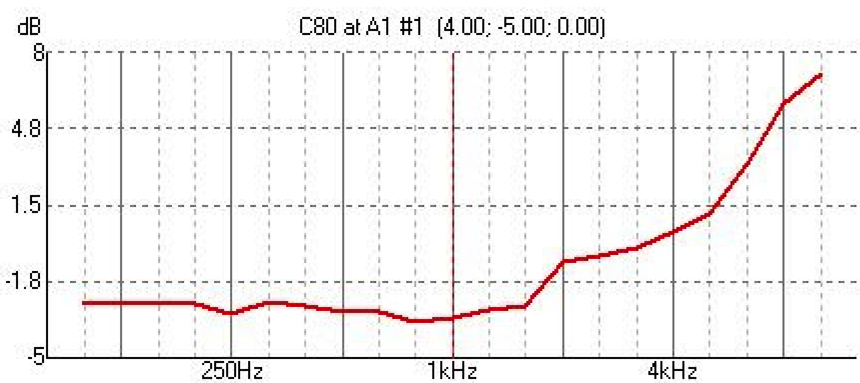

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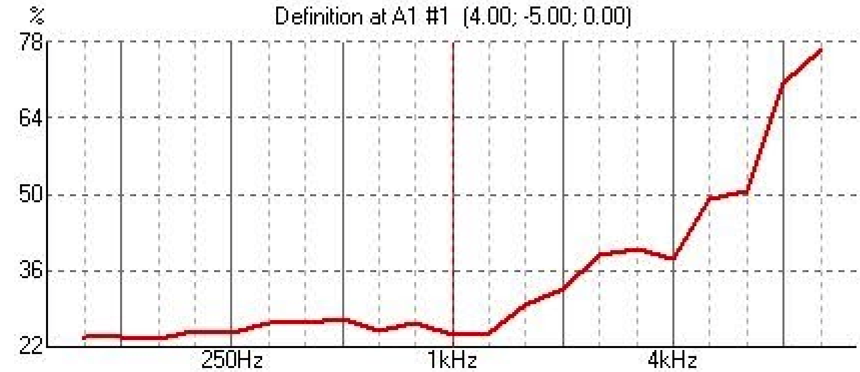

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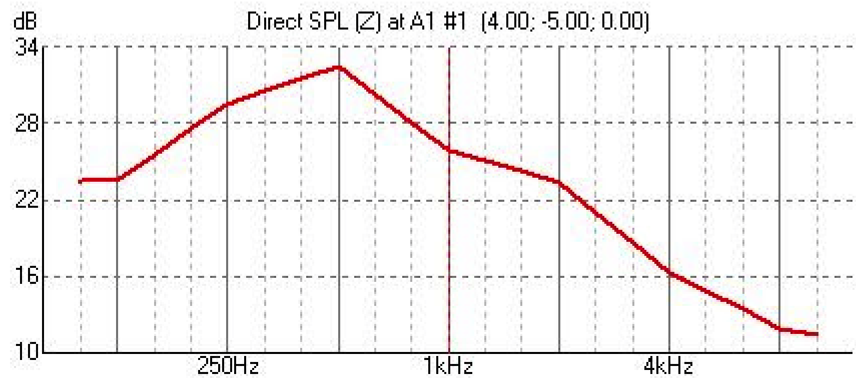

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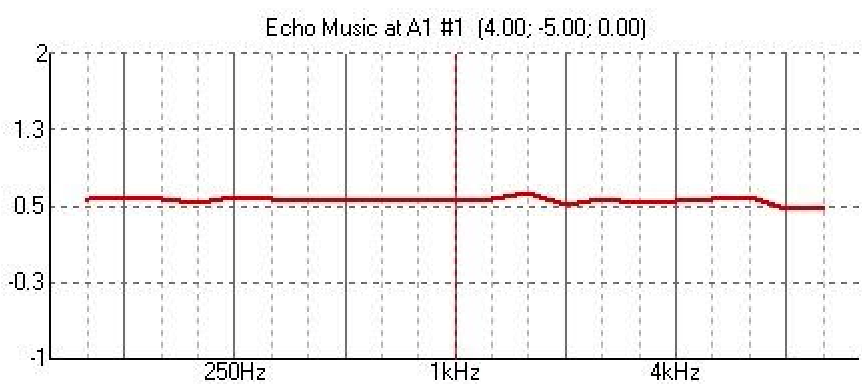

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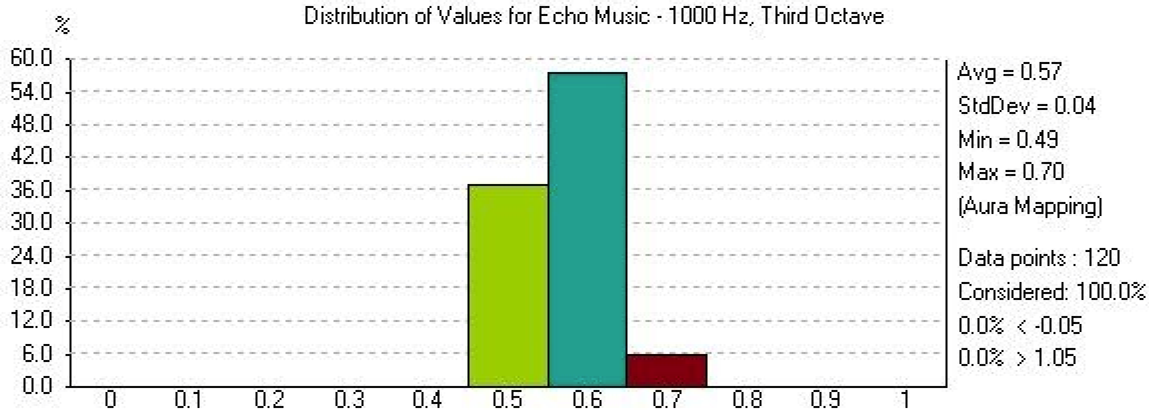

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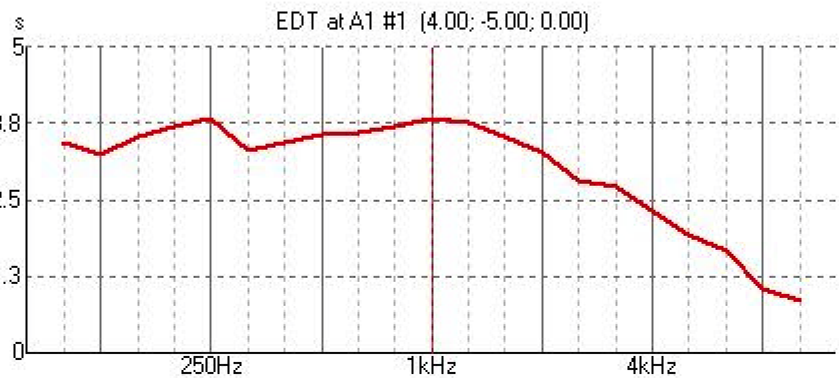

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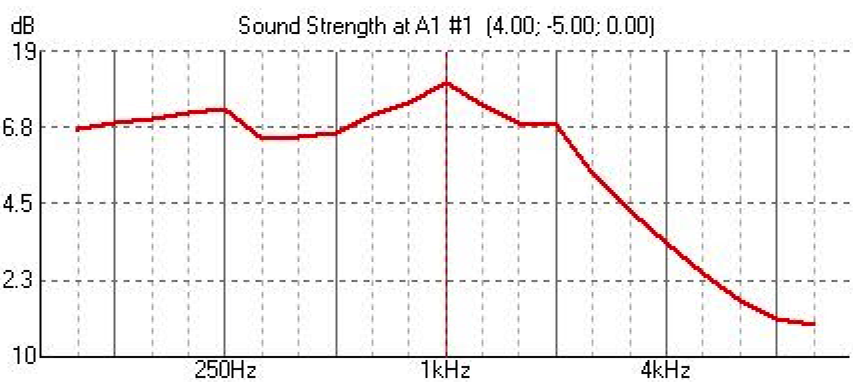

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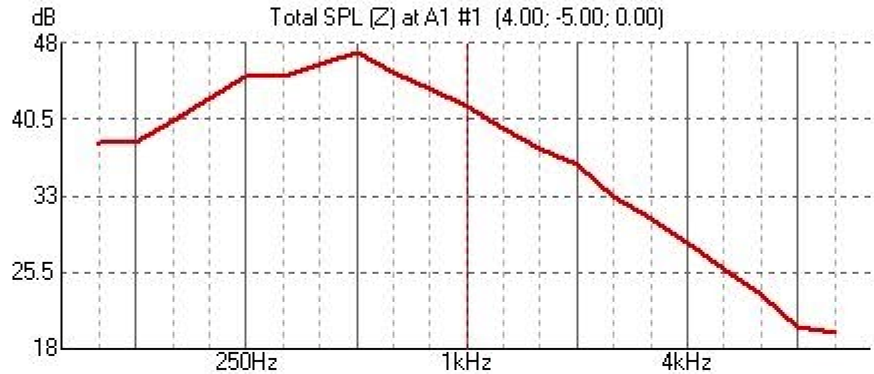

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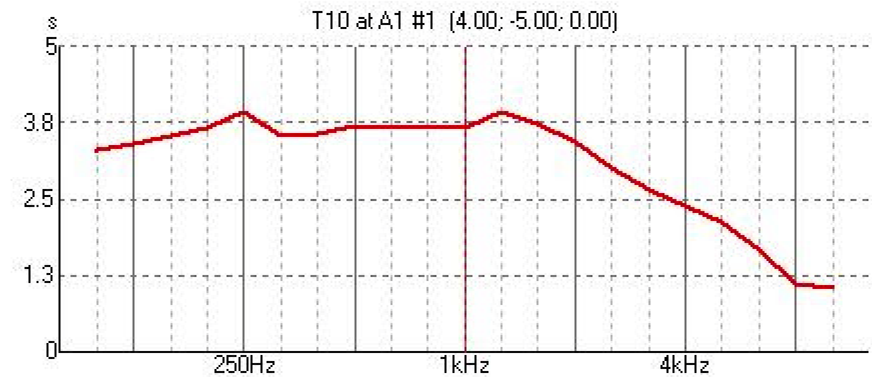

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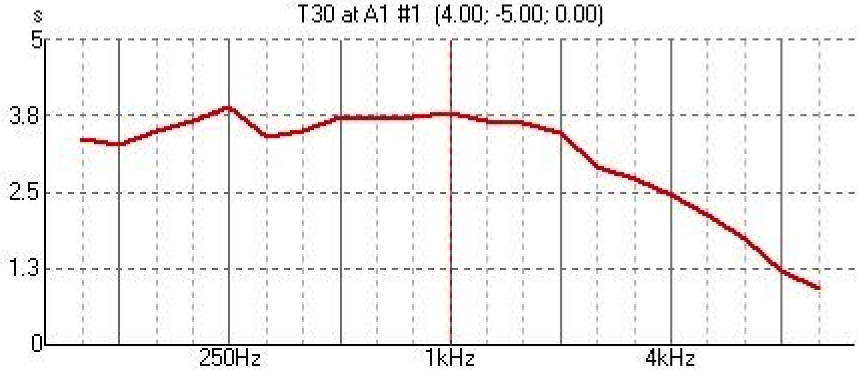

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