DOI: 10.61782/fa.2023.0841

forum acusticum 2023

# CAN YOU HEAR THE PAINTINGS? THE EFFECT OF VOTIVE OFFERINGS ON THE ACOUSTICS OF NOTRE-DAME

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## ABSTRACT

Between 1630 CE and 1707 CE, the Parisian goldsmiths' confraternity donated a series of over 70 large paintings to Notre-Dame as a show of religious devotion. Since the confraternity would present a new painting every year in a ceremony dedicated to Mary on the first of May, the donated paintings are collectively called "the Mays." To paint one of the Mays was a great honor, and the resulting paintings were of monumental scale (with an average area of $12.9\,\mathrm{m}^2$ per painting), typically displayed just below the triforium level of Notre-Dame. Contemporaneous depictions of the cathedral's interior frequently show the Mays hanging along the cathedral's central aisle. Interestingly, in these engravings and paintings of Notre-Dame, there is little consistency in how the paintings are displayed. In some, the paintings hang parallel to the walls, while in others, they are angled downward. Additionally, the mounting height of the paintings changes across illustrations. Treating the Mays as semi-free-hanging acoustic reflectors, the current work assesses the acoustic effect of the materials of the paintings and the different mounting conditions from their installation in the cathedral through the beginning of the French Revolution.


**Keywords:** *Historical Room Acoustics, Church Acoustics, Notre-Dame de Paris*

## 1. INTRODUCTION

Over the 17th and early 18th century, 70 large paintings were commissioned by the Parisian goldsmiths' confraternity and displayed in Notre-Dame. Illustrations of the central aisle of the cathedral show these paintings hanging at different heights and mounting angles. In the present study, the paintings are modeled with different material properties and hanging conditions to examine what effect the paintings would have on the acoustics of the cathedral.

### 1.1 History of the Parisian Goldsmith's Confraternity and the Mays

In medieval France, confraternities [1] (brotherhoods) oversaw the administration of religious and charitable works such as the creation of religious plays, poems, and other creative works [1] in addition to charitable acts for the community [2, 3]. The present study concerns the brotherhood's activities jointly dedicated to Saint Anne and Saint Marcel, a Parisian goldsmiths' confraternity established in 1447 CE [2] and formally recognized at the cathedral in 1495 CE [4]. As a lay organization, the brotherhood's activities within the cathedral were somewhat limited by what the canon body would allow, so the formal acknowledgment and eventual granting of a chapel within Notre-Dame did much to establish the confraternity's actions.

Prior to the establishment of their formal relationship with the cathedral, the brotherhood was active in their veneration of the Virgin Mary at Notre-Dame, starting on May 1, 1449 CE, when they presented a "*May verdoyant*" (green May) at the high altar of the cathedral—a full, leafy-green tree offered as a sign of their devotion to the Virgin [5]. This established an annual tradition of presenting a tree and parading it around the cathedral, a practice that would continue for thirty years. In 1482, the annual ceremony was changed to present a metaphorical green May in the form of poetry, prayers, banners, and tree branches instead of the previously used literal tree. From the beginning of the 16th century, the confraternity created

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[1] Voluntary, guild-associated lay organizations formed for devotional or charitable purposes.

small, gold-covered "tabernacles" to which they would affix their new offerings [4]. Soon, the brotherhood had begun to commission small paintings (*petits Mays*) depicting prophets of the Old Testament to adorn the tabernacles in addition to the other votive objects [4]. Given this escalation of ceremony and its popularity among the general public, it was inevitable that the spectacle of the *petits Mays* would lose its novelty. In April of 1630 CE, the Chapter of Notre-Dame issued a letter granting the brotherhood the right to hang large paintings (*grands Mays*) depicting scenes from the Acts of the Apostles within the cathedral [5]. Throughout the confraternity's existence, a total of 76 *grands Mays* were commissioned. After the introduction of the larger format, the painting would be displayed outside the cathedral on the first of May, processed into the cathedral the next day, and hung in a place of honor from the arcades.

Due to their close association with the medieval guilds, the flourishing of confraternal activities at Notre-Dame parallels the influence exercised by the merchant corporations [6]. In 1679 CE, new royal regulations limited the power of the guilds and confraternities, interrupting the creation of Mays for three years [5]. The financial burden involved in commissioning the paintings and the declining membership of the brotherhood accumulated over the final decades of the brotherhood [5]. In 1707 CE, the confraternity donated its last grand May, and in 1712 CE, membership had declined so drastically that the brotherhood voluntarily disbanded [3].

### 1.2 Size and Location of the Mays

In the initial agreement of donation to the cathedral, the size of the Mays was set at $\approx 3.6\,\mathrm{m}$ tall, but this was expanded to $\approx 4.8\,\mathrm{m}$ in the later years of the tradition [7]. Of the 44 Mays whose locations are known today, [2] the average height and width are $4.1\,\mathrm{m}$ (STD $0.4\,\mathrm{m}$) and $3.2\,\mathrm{m}$ (STD $0.4\,\mathrm{m}$) respectively. One of the earliest Mays, from 1635, has the smallest canvas area at $7.4\,\mathrm{m}^2$, while one of the last Mays, from 1692, is the largest at $16.5\,\mathrm{m}^2$. The average canvas size is $12.9\,\mathrm{m}^2$ (STD $2.8\,\mathrm{m}^2$).

The earliest written description of the Mays' location within Notre-Dame comes from 1648 CE and indicates that the chapter kept the paintings hanging after completing whitening work on the pillars in the nave. After presentation, the Mays were not stationary within the cathedral. Records indicate that they were frequently rotated throughout the cathedral. Even after the donations stopped, they continued to shift throughout the cathedral, eventually reaching a point of stasis where the Mays in the choir were replaced with specifically commissioned large-form paintings depicting the life of the Virgin Mary. The best Mays were distributed in the transept and the others were distributed between the pillars in the nave, side chapels, and entrances [7].

Unsurprisingly, the Mays would be included in visual representations of the cathedral's interior over the centuries, showing the paintings as generally hanging low on the columns or high in the arches between the columns. The mounting angle varies across these depictions, from hanging roughly parallel to the walls or inclined towards the ground to allow visitors to see the scenes better. Examples of these depictions can be found in Fig. 1a (hanging upright on the pillars), Fig. 1b (hanging tilted on the pillars), Fig. 1c (hanging high and upright in the arches between the pillars), and Fig. 1d (hanging high and inclined in the arches between the pillars).

## 2. METHODS

This study aims to understand the acoustic effect of hanging such large canvas paintings in Notre-Dame de Paris. A calibrated geometric acoustic model of modern Notre-Dame (ca. 2015) [8, 9] was used as a starting point. Modifications to the historic model were then carried out using a similar philosophy as in [10, 11], where primary sources, writings by historians, and depictions of the interior of Notre-Dame from engraving and paintings are used to inform changes to the geometry and materials of the cathedral. Simulations were run with CATT-Acoustic (v9.1g) using algorithm 1 with 1 000 000 rays. [3]

### 2.1 Theory

The acoustic properties of materials are often described in terms of how they reflect, absorb, and transmit energy. The absorption coefficient ($\alpha$) is the ratio of acoustic energy absorbed relative to an incident wave, and the transmission coefficient ($\tau$) is defined as the ratio of acoustic energy transmitted through the material relative to an incident wave. In room acoustics (in contrast to building acoustics), energy transmitted through boundary surfaces such as walls and windows is considered part of the energy lost from the room. In these cases, the $\alpha$ coefficient represents both losses due to dissipation and transmission. With interior reflectors, such as paintings and

[2] Some of the Mays have been damaged, destroyed, or lost.

[3] `https://www.catt.se/`

(a) Vue de l'intérieur de Notre-Dame avec le tabernacle du may, XVII siècle. Photo by Bénédicte Colly. ©Société des amis de Notre-Dame de Paris.

(b) Vue intérieure de Notre Dame, by Aveline. Musée Carnavalet G.52918. CC0 public domain.

(c) Vue intérieure de Notre-Dame, en 1789, by Jean-François Depelchin. Musée Carnavalet P98. CC0 public domain.

(d) Vue de l'intérieur de l'Eglise de Notre-Dame en 1789, anonymous engraving. in "Tableau historique et pittoresque de Paris" BnF. CC0 public domain.

**Figure 1**: Depictions of the Mays hanging on the columns (Figs. 1a and 1b) and in the arches between the columns (Figs. 1c and 1d) along the central nave of Notre-Dame.

free-hanging tapestries, energy transmitted through the artwork remains in the same room. Thus, both the $\alpha$ and $\tau$ coefficients are needed for accurate simulation. Absorption and transmission are frequency dependent and are related to the characteristic impedance ($Z$) at the surface of the material. Derivation of these physical properties and relationships is beyond the scope of this paper, and the reader is referred to one of the many textbooks on the topic (e.g., [12]).

### 2.2 Acoustic Properties of Paintings

There are very few sources in the literature that discuss the acoustic properties of paintings (see Table 1). [13] reports diffuse-field absorption coefficients of paintings and tapestries measured in a classroom using the reverberation chamber method (ISO 354:2003). The authors observed that primed, oil-painted canvases act as impermeable membranes. In that work, the painting was flat on the ground and only absorption coefficients were reported. Using the impedance tube method (ISO 10534-1:2001), [14] demonstrates that the peak of the absorption coefficient moves lower in frequency and higher in amplitude as a function of the thickness of the oil paint. It should be noted that the mounting condition significantly affects the observed absorption due to the air-gap behind the painting and the material properties of the surface be-

**Table 1**: Oil painting absorption coefficients in the literature (those from [13] are used in this study). As transmission coefficients are not reported in the literature, the $\tau$ values used in this study are also listed.

| | 125 | 250 | 500 | 1 K | 2 K | 4 K |
|---|---|---|---|---|---|---|
| $\alpha$ [13] | 0.001 | 0.001 | 0.01 | 0.1 | 0.2 | 0.45 |
| $\alpha$ [14] | 0.01 | 0.02 | 0.18 | 0.25 | 0.19 | 0.14 |
| $\tau$ | 1 | 0.95 | 0.8 | 0.5 | 0.4 | 0.3 |

hind the painting. [14] presents impedance tube measurements showing that the peak of the absorption coefficient moves lower in frequency and higher in amplitude as the air-gap behind the canvas increases. As canvas paintings are often mounted flush on walls, $\tau$ coefficients have not been widely reported in the literature.

### 2.3 Analysis of Low-Order Reflections

Before modeling the Mays hanging in Notre-Dame, preliminary geometric simulations were run to evaluate when low-order reflections off the paintings would arrive to listeners in the nave. The justification for this approach is that the time of arrival (TOA) of low-order reflections may impact speech clarity ($C_{50}$) while higher-order reflections likely contribute more to other room acoustics metrics such as reverberation time.

Figure 2 shows a schematic section spanning the width of Notre-Dame showing the positions of the paintings, sources, and receivers investigated with the image source method (ISM). Two rows of eight paintings $3\,\mathrm{m} \times 4\,\mathrm{m}$ in size were modeled as perfect reflectors to analyze low-order reflections. The inter-painting spacing within each row was $5.85\,\mathrm{m}$, corresponding to the size of the bays in Notre-Dame, and the bottoms of the paintings aligned in each row were $12.5\,\mathrm{m}$ apart from each other, corresponding to the width of the main nave of Notre-Dame. The paintings were mounted at two heights: with the bottom edge of the painting $3\,\mathrm{m}$ above the ground, similar to the depictions of the Mays hanging on the columns, and at $7\,\mathrm{m}$, corresponding to the depictions of the Mays hanging between the columns above their capitals.

In the depictions of the interior of Notre-Dame, the paintings can be seen hanging at a variety of angles (see Fig. 1). The open source software fSpy [4] was used to estimate the perspective portrayed in several of these engravings [15]. This perspective analysis revealed that the

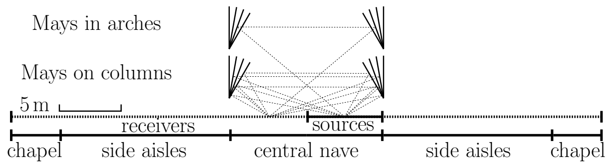


**Figure 2**: Elevation view showing painting height and angle and source/receiver positions for ISM modeling. Dotted lines indicate example low-order reflections for a single source /receiver pair.

paintings are depicted as tilting between approximately 0° to 26°. It should be noted that there is some inherent error in this analysis as the artists do not always render perspective and dimensions accurately. As a general approximation study to cover this possible range, the paintings in the acoustic model were then simulated hanging upright through 30° tilt towards the center in 5° steps.

The geometry of the various hanging conditions was evaluated with the image-source method using source positions spanning a point equidistant from both rows of paintings (i.e., the center of the nave) to directly under one row of paintings (i.e., one edge of the central nave) with a height $1.2\,\mathrm{m}$ above the floor. Receivers spanned $\pm 22\,\mathrm{m}$, a distance equivalent to the width of Notre-Dame including the side chapels and side aisles.

When mounted at $3\,\mathrm{m}$, first-order reflections (a reflection off a single painting) arrive between $30\,\mathrm{ms}$ to $70\,\mathrm{ms}$ after the direct path across the full width of the cathedral, so long as the paintings are tilted more than about 7°. Second-order reflections (reflected between the two rows of paintings) typically arrive between $25\,\mathrm{ms}$ to $80\,\mathrm{ms}$ and only in the central nave. For the second-order reflections, TOA tends to decrease as the mounting angle increases.

When the paintings are mounted at $7\,\mathrm{m}$, low-order ISM reflections that hit the floor only start appearing beyond 10° tilt. At low angles, second-order reflections typically appear only beyond the rows of paintings (i.e., in the side aisles and chapels) and arrive around $80\,\mathrm{ms}$ after the direct sound. First-order reflections do not manifest until the paintings are tilted about 20° and arrive just under $80\,\mathrm{ms}$. As the mounting angle increases, the TOA for first-order reflections decreases to between $60\,\mathrm{ms}$ to $75\,\mathrm{ms}$, and a larger amount of first-order reflections arrive in the central nave. The TOA for second-order reflections decreases to $70\,\mathrm{ms}$ to $85\,\mathrm{ms}$, also mostly in the central nave.

In isolation, it seems that if the paintings are mounted

[4] `https://fspy.io/`

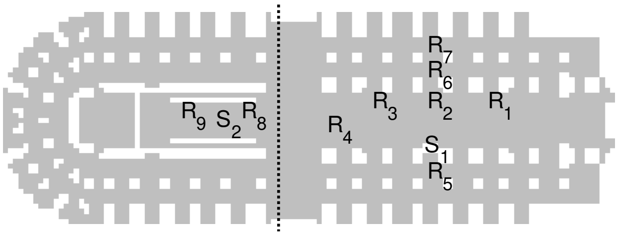


**Figure 3**: Plan view of Notre-Dame showing simulation source and receiver positions.

low and on the columns, some reflections may arrive close enough in time to the direct sound that they could enhance speech clarity. That said, for a large portion of source/receiver positions and for the high-mounted conditions, the majority of low-order reflections arrive later than $50\,\mathrm{ms}$ and would reduce $C_{50}$. In Notre-Dame and other similar cathedrals, most early reflections in the nave come from the columns and piers [16]. Naturally this preliminary analysis is overly simplified as it does not include specular reflections or contributions from the floor and columns.

### 2.4 Upper Bounds on Material properties

Following the preliminary analysis using low-order ISM reflections, the various painting mounting conditions were evaluated in a geometric acoustic model of the nave of Notre-Dame. As the mounting conditions of the paintings in the transept and chancel differ from that of the nave, these portions of the cathedral were excluded from the simulation. Since the material properties of the Mays could not be measured, limits on the effect of including the paintings in the model were assessed by comparing the painting-less baseline to simulation extremes with paintings modeled as either fully absorptive ($\alpha = 1$) or fully reflective ($\alpha = 0$) to ascertain the bounds within which the acoustic contribution of the painting could be, specifically within perceptual limits.

Figure 3 shows a plan view of Notre-Dame marking simulation source and receiver positions used in Sections 2.4 and 2.5. The sources are in the nave pulpit and center of the choir, selected as likely locations for preaching in the cathedral. Receiver positions were informed by the ISM results (Section 2.3) as well as selected to span the cathedral. This figure also shows the eastern bound of the nave-only model. In addition to the baseline simulation of the nave without paintings, the paintings were modeled for two mounting positions (low on the columns and high in the arches between the capitals of the columns), for two mounting angles (upright and titled 30°), and for two material properties (fully absorptive and

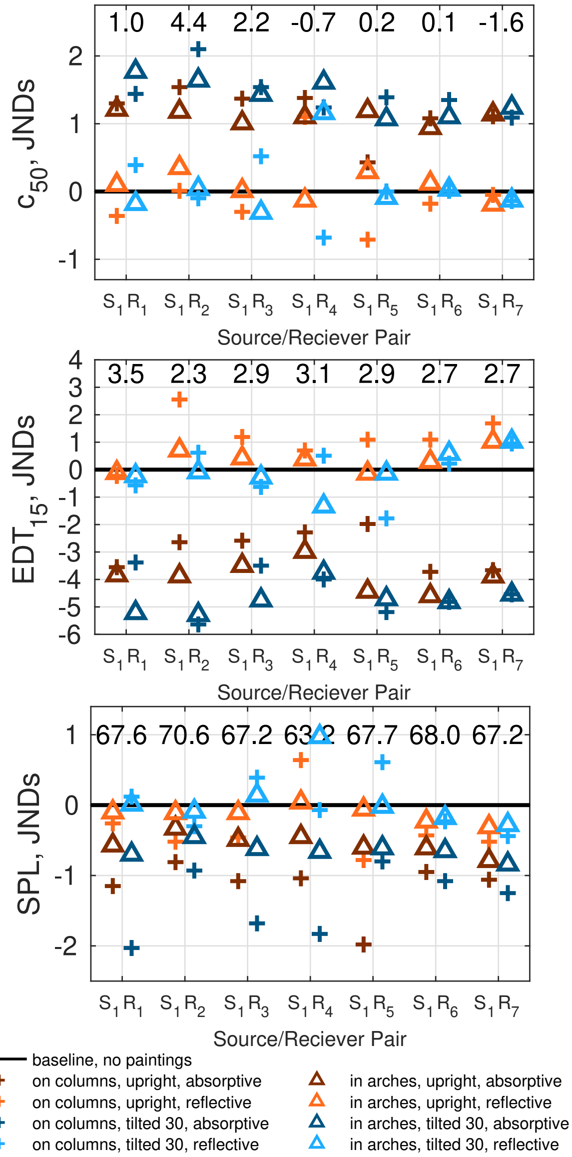


**Figure 4**: Notre-Dame nave model $C_{50}$, $EDT$, and $SPL$ as a function of painting mounting condition in units of JND ($1\,\mathrm{dB}$ for $C_{50}$ and $SPL$ and $5\,\%$ for $EDT$). The values of the baseline room acoustics parameters are displayed along the top of the graphs.

fully reflective) yielding eight additional simulations. Figure 4 shows comparisons of $C_{50}$, $EDT$, and $SPL$ for the different conditions across receiver positions in the nave. In these figures, the y-axes are centered around the baseline (no painting) condition and are displayed in units of the JND for the various room acoustic parameters.

It is readily apparent that modeling the paintings as absorbers has a more significant effect on these room acoustic metrics than modeling the paintings as reflectors. The primary material of the cathedral is limestone and absorbs very little energy in the audible range. Therefore, reflections from the paintings modeled as reflectors will not differ significantly in amplitude compared to those from the columns, vaults, walls, and floor. Figure 5 shows a comparison of a Notre-Dame nave RIR without paintings compared to an RIR of reflective paintings without the room. The strong, first-order reflection of the reflective painting is not significantly louder than other room reflections and would not be audibly identifiable.

No reflections will be created from rays that hit the paintings modeled as total absorbers. Because of this increase in energy dissipation, the reverberation time decreases significantly. For most receiver positions, $C_{50}$ increases by more than $1\,\mathrm{dB}$ and $EDT$ decreases by nearly $0.5\,\mathrm{s}$ (both larger than the generally accepted JNDs) for all absorptive simulations. The changes to $C_{50}$ and $EDT$ for the reflective conditions are much less significant and rarely exceed the JND.

Comparing differences caused by the mounting height and angle is also interesting. In particular, the $EDT$ is lower and the $C_{50}$ higher when the absorptive paintings are tilted rather than straight up and down. This can be explained by the property that tilted paintings would reflect upward-moving acoustic energy toward the ground while flat mounting would not. In the absorptive case, strong early reflections are eliminated. While the $SPL$ is generally lowered for the absorptive conditions, only the conditions where the Mays are mounted low on columns exceed the JND for most receiver positions. Here the contrast between the upright and tilted conditions is also shown clearly—the tilted condition is nearly another $1\,\mathrm{dB}$ lower than the upright condition.

### 2.5 Modeling the Mays in Notre-Dame

Simulations were run in the full geometric model of Notre-Dame (not truncated nave as in Section 2.4) with realistic material property configurations assigned to the paintings. $\alpha$ coefficients for “medieval” oil-painted canvas were taken from [13]. Theory from [12, 17] was employed to set $\tau$ coefficients where the paintings are acoustically transparent at low frequencies and more reflective at high frequencies (see Table 1 for values employed). In addition to the sixteen paintings lining the central aisle of the nave, twelve paintings were added to the transept and six above the choir stalls. To align with the many historical depictions of the interior of Notre-Dame, the paintings were mounted with a tilt of $12°$.[5] The paintings in the transept and choir were mounted at $7\,\mathrm{m}$. Conditions with the paintings mounted low on the columns and high in the arches above the column capitals were simulated, compared to the baseline painting-less condition. The cathedral was simulated with omnidirectional sources located in the nave pulpit and the center of the choir.

Figure 6 shows $T_{30}$ averaged across positions and $C_{50}$, $EDT$, and $SPL$ as a function of source/receiver position. With realistic material properties and mounting conditions, there is no predicted perceptual difference in room acoustic metrics for reported source/receiver pairs.

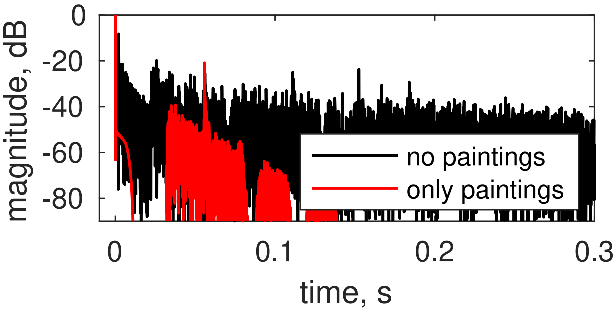


**Figure 5**: Log RIR of Notre-Dame nave without paintings overlaid with RIR of reflective paintings with no room for source $S_1$ and receiver $R_2$ with low-mounted, reflective paintings tilted $20°$; first-order reflection at $T = 56\mathrm{ms}$.

### 3. DISCUSSION

Perhaps it is disappointing to suggest that a large collection of massive paintings likely had a very little perceptual effect on the acoustics of Notre-Dame. The 34 paintings inserted into the acoustic model added about $800\,\mathrm{m}^2$ of (slightly) absorptive material.[6] Considering Notre-

[5] See [7, A5§3] for more views of the interior of Notre-Dame.

[6] As the paintings are not flush mounted, this surface area accounts for the front and backs of the paintings.

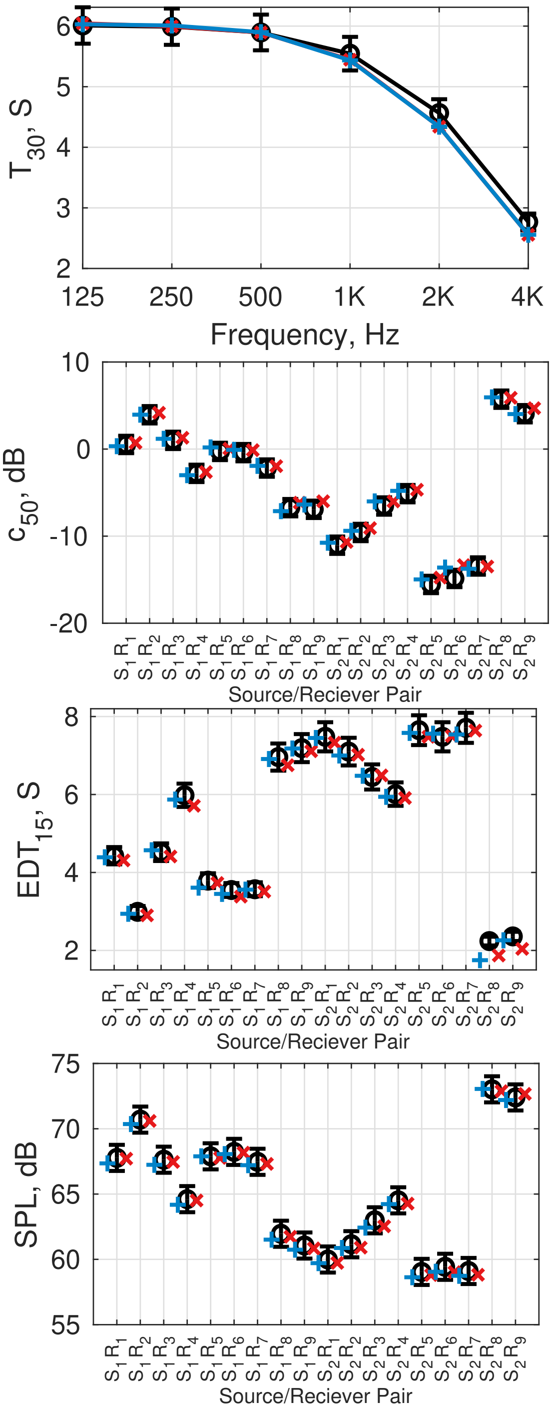


**Figure 6**: Full Notre-Dame model, octave-band $T_{30}$, $C_{50}$, $EDT$, and $SPL$ as a function of painting mounting condition. ○: no Mays; +: nave Mays on columns; × nave Mays in arches. Error bars show the JND of the room acoustic parameters.

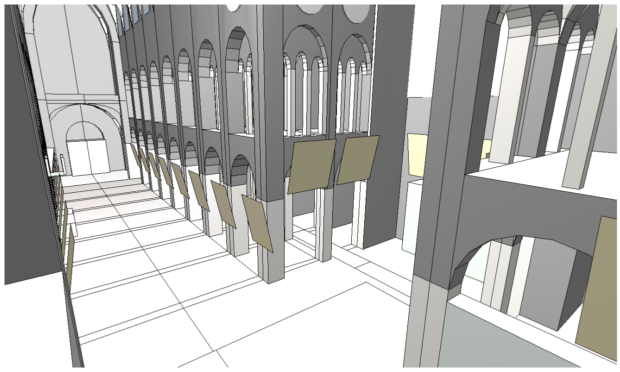

**Figure 7**: Interior view of Notre-Dame acoustic model showing paintings on nave columns, in the transept, and in the choir.

Dame has an internal volume of approximately 91 000 $\mathrm{m}^3$ and a total surface area approaching 34 500 $\mathrm{m}^2$, the inclusion of the Mays adds/modifies a relatively small percentage of material to the total surface area of the cathedral ($\approx$2 %). The changes in room acoustics parameters observed [17] were more significant than those seen in the current study. This can be explained as they included a larger percentage of more absorbent material (tapestries) into their model than are represented by the Mays in Notre-Dame. In Notre-Dame, other absorbing materials added to the cathedral for festivals, such as draped velour curtains, textiles wrapping the columns, a large carpet in the choir, and most importantly, a large number of people, likely would have a more significant effect on the acoustics of the cathedral than the Mays.

In this work, non-physically realistic maximum/minimum absorption values were tested for the paintings mounted in a truncated nave acoustic model. With these extreme material properties, changes to $C_{50}$ and $SPL$ remained mostly within 2 JNDs of the baseline condition without the paintings, while $EDT$ changed by a more significant amount. When more realistic materials properties are used for the paintings, these room acoustics parameters do not change significantly. While a few references propose absorption coefficients for paintings, the actual acoustical properties of the Mays remains conjecture. Large paintings like the Mays probably have a wooden support structure in addition to a frame, and in contemporary conservation practice, there is usually a backing material (such as cardboard, foamcore, acrylic, or wood) behind the painting to protect it dust and humidity [18, 19]. The addition of these materials may also contribute to the acoustic effect of hanging paintings.

While some sources (e.g. [13] and [14]) report absorption coefficients for paintings, none to our knowledge report transmission coefficients. Many large paintings are hung with some tilt where the bottom edge touches the wall or column behind it while the top can be offset by tens of centimeters. Considering the significant effects of air gaps and mounting techniques, it would be valuable to make measurements and further study the acoustic effects of such styles of paintings.

After the restoration of Notre-Dame is complete, some of the Mays may return to the cathedral. Musicians familiar with the cathedral have expressed concern that the re-installation of paintings may have negative effects on the organ and vocal music [20]. The current study's simulation results do not support such concerns.

## 4. FUNDING

Funding has been provided by the European Union's Joint Programming Initiative on Cultural Heritage project PHE (Grant No. 20-JPIC-0002-FS), the French project PHEND (Grant No. ANR-20-CE38-0014), and the Chantier scientifique Notre-Dame de Paris Ministère de la Culture/CNRS.

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