



SEARCHING FOR THE LOCATION OF THE FIRST MEDIEVAL ORGAN IN NOTRE-DAME DE PARIS VIA ACOUSTIC SIMULATION

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ABSTRACT

The location of the 14th century organ in the Cathédrale Notre-Dame de Paris is based on conjecture. Acoustic simulations are employed to investigate the possible position of the instrument according to historical sources. A historically-informed 3D geometrical acoustic model of the cathedral allows for numerical simulations of a virtual instrument positioned inside the church. For the period in question, the liturgical choir and the nave are furnished in the medieval style with wooden stalls, tapestries, and a jubé and clôtüre enclosing the chancel. Acoustic effects of six positions for the organ (at the western tribune, as a swallow's nest hung on the south wall of the second and fifth bays, on the jubé, in the southern transept, and above northern stalls in the choir), three conditions for its elevation (ground level, triforium, and clerestory), and occupied (festival)/unoccupied (ordinary day) conditions are evaluated. SPL and center time are reported across the ground level of the church. A comparison of the different conditions indicates strong effects of occupation (less intense but clearer sound), position (on audibility), and elevation (on clarity). Finally, the likely position of the first medieval organ is discussed.

Keywords: *pipe organ, room acoustics, archeoacoustics, Notre-Dame de Paris*

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1. INTRODUCTION

Permanently installed pipe organs began appearing in large churches and cathedrals in the second half of the 14th century onward and assumed a growing role in liturgical, devotional, and social activities [1, 2]. At least two Gothic organs were built in Notre-Dame de Paris in the 14th (*Organ I*) and 15th (*Organ II*) centuries. The two earliest mentions of an organ appeared in the registers of the chapter of Notre-Dame, in 1332 (payment of an organist to play the organ) and 1333-1334 (placement of a bell in the choir for use with the organ) [3]. This may correspond to a prior small, portable 14th century instrument, *Organ 0*.

It is believed that Organ I was built in the second half of the 14th century, during the installation of the clôtüre, the jubé, and stained-glass throughout the cathedral. Organ I is known essentially through scarce information in the registers of the chapter of Notre-Dame when it was dismantled in 1426: the tin pipework weighed 800 *livre*; the instrument occluded a window on an exterior wall; six assistants operated the bellows via a wheeled blowing engine. In addition, the organ was quoted as a “large organ” by a visitor in 1414 [4]. Compared to Organ I, documentation related to Organ II is relatively abundant, mainly because of the successive price quotes from the organ builders that restored the instrument until the 18th century, when it was completely rebuilt in the classical style. Another acoustic clue for Organ I is the presence of a bell in the choir to communicate with the organist. This bell seemed necessary because the sound of voices and/or visual contact may not have been prominent enough to be perceived by the organist.

A noticeable change occurred when Organ II was constructed during the years 1401–1403. Instead of enlarging



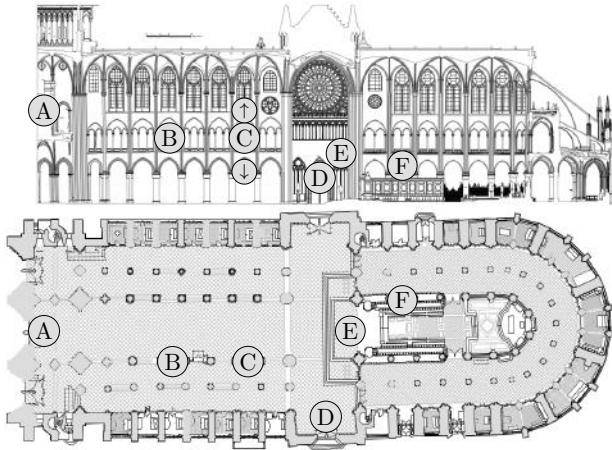


Figure 1: Elevation and plan of Notre-Dame showing organ positions under study: (A) the 15th century Organ II, (B) and (C) possible positions of the 14th Organ I, (D) south transept, (E) on the jubé, (F) 19th century choir organ.

Organ I, this second instrument was located in the west above the cathedral's entrance (see Fig. 1). Note that Organ II was offered to the canons by a layman, Duke Jean de Berry, a famous patron of the arts. This displacement towards the west may reflect the growing political role played by the cathedral in the second part of the Hundred Years War. The eastern part of the cathedral was reserved for clerics and the western part was open to laypersons and the city. Solemn entries of important persons through the western portal would be accompanied by the sound of trumpets outside and the organ inside [5].

In the 14th century, the function of the organ was reserved for 23 high feasts and other special occasions throughout the year. The repertoire (written and improvised) is scarcely known, mostly by *posterior tablatures* and written reports. The instrument fulfilled two principal functions in close relationship with the liturgy performed inside the chancel and to the activity in the nave. First in dialogue with, and possibly accompaniment of, the choir hidden inside the chancel and second as introduction and conclusion of the liturgy, accompaniment of processions, and “*entrée solennelle*” of important personages like kings or visitors [4].

The present study aims to contribute to a better knowledge of these lost instruments using acoustic simulations. These simulations examine the audibility of the instru-

ment, depending on its position in the nave, its elevation, and the occupation conditions of the church.

2. ACOUSTIC SIMULATIONS

A historically-informed geometrical acoustic model of the cathedral allows for numerical simulation of a virtual instrument positioned within the church. This model was based on a previously calibrated model of Notre-Dame [6], with the integration of subsequent time-regressions to arrive at its medieval state (see [7, 8]). Historical sources indicate that the organ would have been used primarily on the high feasts of the Christian calendar [4], so the model was further modified to reflect a high festival state of decorations.

2.1 Architecture and furnishing

As the cathedral had reached a place of architectural stasis by ca. 1350 [8], most alterations from previously reported models come in the form of interior decorations. At this time, the choir was furnished with wooden choir stalls in a horseshoe shape with carpets laid on the ground at significant positions (underneath the Archbishop's feet, for instance) and tapestries hung from the back of the stalls facing inwards towards the canons. Additionally, the choir and high altar were physically separated from the ambulatory of the chancel by a highly decorated stone *clôture* depicting Biblical scenes [9]. The transitional space between the choir stalls and the transept crossing was further buttressed by a *jubé*—a choir screen that served as one of the stations in religious processions and a platform from which music and scriptures were declaimed [10, 11].

An exemplary depiction of the choir in this state can be found in the lithograph depicted in Fig. 2, created by architect Daniel Marot at the end of the 17th century. While this depiction postdates the focus of this article by approximately 200 years, it was drawn before a series of significant renovations to this area and served as a useful visualisation of the more decorative approach common to the pre-Baroque era. The medieval *jubé* and the high backs of the westernmost choir stalls have been omitted in this engraving to reveal the interior of the choir. The tapestries on the interior side of the choir stalls are clearly visible, as is the *clôture* at the easternmost end of the sanctuary. Other decorations, including the overhanging canopies above the choir stalls, the high altar and its surrounding tapestries, and the *feretory* containing the most precious relics behind the high altar, can be seen in the background.

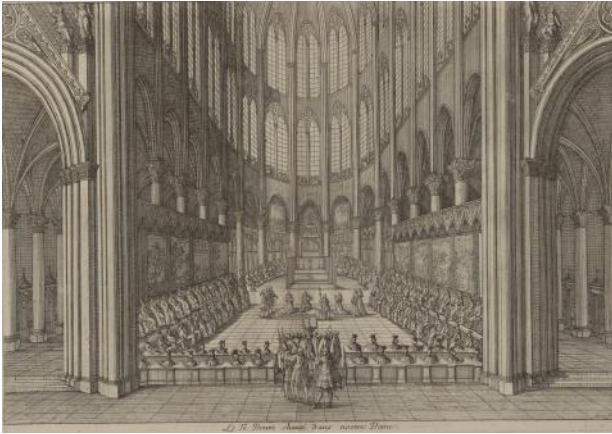


Figure 2: *Le Te Deum chanté dans nostre Dame*, engraving by Daniel Marot. Musée Carnavalet CC0 public domain.

Historical records indicate that the lateral chapels were individually furnished by patrons and confraternities of the cathedral, with a wide range of decorative states possible depending on the tastes of the chapel's sponsors [12, 13]. It was common to wrap the cathedral's columns with decorative cloths for high feasts and hang banners from the triforium level of the nave [4].

The acoustic model was revised to reflect the decorations of the liturgical choir and lateral chapels, furnishings in the ambulatory, and the addition of fabric wrapping the columns on each side of the nave's center aisle. Additionally, the nave was populated with the type of crowd expected on such a solemn day as Christmas, Easter, or other significant days of the calendar (density of 2 people per 3m^2 , drawn from measurements of worshipers reported in [14]).

2.2 Organ source

For all simulated organ positions except the one on the jubé (E), the directivity of a small proxy organ, representing an organ buffet, measured in anechoic conditions was used [15]. This laboratory instrument comprised a plywood box $134\text{ cm} \times 98\text{ cm} \times 58\text{ cm}$ with 136 foam-filled PVC tubes. For the position on the jubé, an omnidirectional directivity was used as an organ in such a location would likely have two façades (one facing the choir and the other the nave). The organ sources were set at an output level of 100 dB at 1 m with a pink noise spectrum.

2.3 Potential organ locations

Documentation for Notre-Dame indicates the presence of an occluded (plastered) window behind the instrument, thereby excluding the jubé (E) and western tribune (A) as plausible positions. A location in the chancel is also excluded as the chancel was surrounded by a clôtüre at the time of Organ I. Portions of the 14th century clôtüre are still in place with no apparent trace of the presence of an organ. Moreover, organs located in chancels are scarcely found in northern French churches. The transept (D) also seems excluded because of its decoration, the absence of windows except for the large roses, and the lack of space for the bellows and their servants. The large tribunes above the nave offer sufficient space to lodge the blowing engine and are easily accessed by stairs. Evidence from iconography, archives, and partially preserved instruments point towards a location protruding from this level (a configuration sometimes called a swallow's nest), somewhere in the nave. However, the position in the nave is unsure. The southern wall is most likely (B and C), because of its better climatic conditions (it is dryer) and because the indication of a plastered window suggests the need to avoid direct sunlight (that is brighter on the southern wall).

2.4 Metrics

In order to assess the audibility and suitability of various hypothetical organ positions in Notre-Dame, sound pressure level (SPL) and center time (T_S) were computed across the ground floor of the cathedral. Mapping SPL as a function of listening position in the cathedral allows us to visualize the areas of the cathedral where the organ will be the loudest and quietest. Comparing the various hypothetical organ positions demonstrates the ways various zones of the cathedral (e.g., stall in the choir, position in the apse-end of the nave, or in a side chapel) are affected by the location of the organ. Due to the exploratory nature of these comparative simulations and to highlight significant differences, SPL contour maps show 3 dB delimitations.

Center time is selected as a proxy to assess musical intelligibility. T_S is expressed in ms and equates to the time when the cumulative early and late arriving energy are equal [16]. Thus positions close to a source typically show low T_S as the energy of the direct sound and early reflections will be significantly greater than the energy in the late reverberation. In contrast, positions far from a source typically exhibit a greater T_S as the direct sound

will be quieter (or absent when the source is occluded) relative to late arriving energy.

T_s is chosen over clarity metrics like C_{50} and C_{80} , which are based on time limits related to the analysis of common speech phonemes and average note lengths for classical music, respectively. Center time does not impose context-dependent time integration limits [17]. For comparison, $C_{80} = 0\text{dB}$ equates to $T_s = 80\text{ms}$. As the reverberation time of a cathedral is significantly longer than that of a concert or lecture hall, and the structure of medieval music is extremely different from classical music or speech, center time seems like a more suitable metric for evaluating musical clarity in the context of organ music in Notre-Dame. As [18] shows that the JND for center time in spaces with large reverberation is related to a percentage of the nominal T_S time, the T_S contour maps use a logarithmic time scale.

3. RESULTS AND DISCUSSION

3.1 Acoustic effect of organ location

Figures 3 and 4 show contour maps of SPL and T_S comparing six organ positions ranging from east to west in the cathedral in the unoccupied condition (Fig. 1), comprising the position of the modern choir organ (F), on the medieval jubé (E), in the arm of the transept (D), at the 2nd (C) and 5th (B) bays of the nave, and in the tribune (A).

These results examine the acoustic behavior of the organ as a function of position in Notre-Dame. Overall, it is apparent the modern choir organ position (F) on the clôtüre of the choir provides the highest SPL and lowest T_S in the consecrated portions of the cathedral, while organ positions in the nave provide higher SPL and lower T_S in the central nave.

As Organ I was likely along the triforium level in the nave, comparing locations (B) and (C) is interesting. The SPL is relatively high and uniform throughout the nave for both positions. Due to its proximity to the apse, an organ positioned in the 2nd bay would be louder within the choir than the more distant organ in the 5th bay.

Organ II, located below the western Rose window (A), has a very similar SPL to that of an organ positioned in the 5th bay (B) both in the central nave and in the chancel. However, since it faces east towards the transept, the T_S remains lower at greater distances along the main axis of the cathedral. The distance to the choir is significant. Such a position is well suited for events such as solemn entrances, processions, and *alternatim*

(call/response) with singers in the choir. However, the accompaniment of polyphonic music in the choir would be difficult, if not impossible, because of the acoustic propagation delays due to the large distance (propagation time of $\approx 175\text{ms}$ from the organ (A) to the jubé), far exceeding acceptable delays for ensemble playing [19].

Positioning the organ in the transept (D) does not seem particularly effective in Notre-Dame. As discussed in [10], the large volume of the transept impedes sound transmission between the nave and apse of the cathedral. As the transept of Notre-Dame is quite deep, an organ there would not have a visual line-of-sight with most of the nave. Consequently, an organ in the transept would likely only be effective for those in the first few bays in the nave.

While we know the organ was not located on the jubé (E) in Notre-Dame, this position seems musically desirable. Its proximity to the chancel means the SPL is high and the T_S low within the choir stalls. Its location also privileges the easternmost portion of the central nave. Finally, like the organ positioned below the western rose window (A), its position on the central axis of the cathedral provides a uniform gradient of SPL and T_S down the cathedral's central aisle.

3.2 Acoustic effect of elevation

Figure 5 shows SPL and T_S for an organ positioned in the 2nd bay of the nave (C) at three different heights: at the level of the triforium, elevated 8 m (covering the window one level higher), and lowered 5.5 m (at the height of 19th century choir organ).

The elevated position does not significantly change the SPL in the cathedral except in the portion of the nave directly opposite the location of the organ. However, raising the height of the organ significantly decreases T_S throughout the entire cathedral. From an elevated position, the direct sound path will be longer from all listening locations on the ground and diffuse late energy will begin earlier.

The lowered position, below the triforium, increases the SPL in the eastern half of the nave. Likewise, closer proximity decreases the center time in this area of the nave, equating to increased clarity.

3.3 Acoustic effect of occupation

Figure 6 shows SPL and T_S for the organ positioned at the triforium level of Notre-Dame in the 2nd bay (C) for the unoccupied state and modified to reflect the cathedral

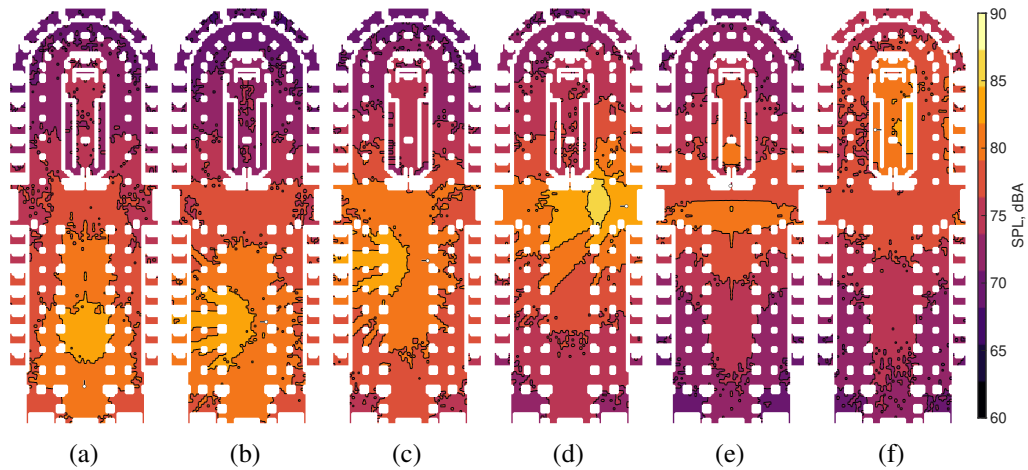


Figure 3: Simulation results of SPL (A-weighted) for unoccupied condition. Organ positions from west to east: in the tribune, in the 5th bay, in the 2nd bay, in the transept, on the jubé, location of the contemporary choir organ.

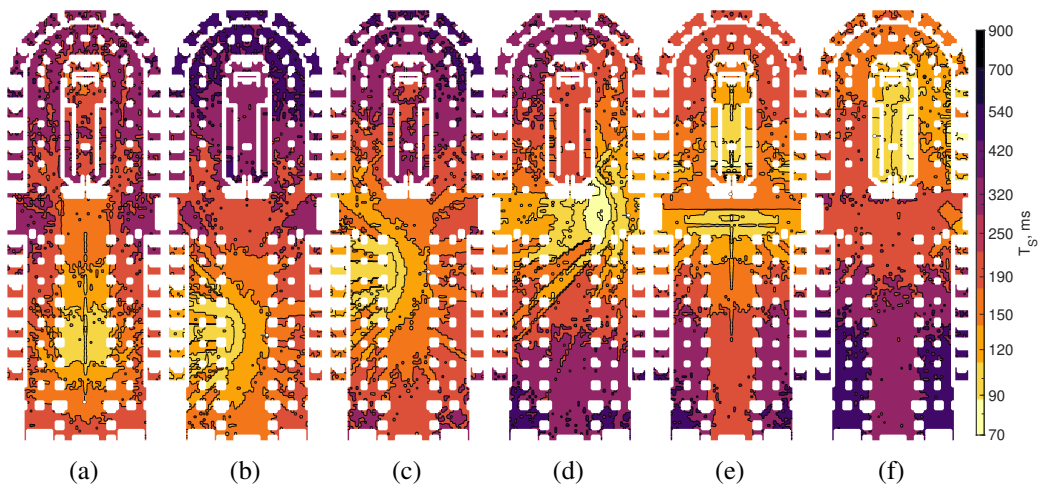


Figure 4: Center time (T_S) for unoccupied condition. Organ positions from west to east: in the tribune, in the 5th bay, in the 2nd bay, in the transept, on the jubé, location of the contemporary choir organ.

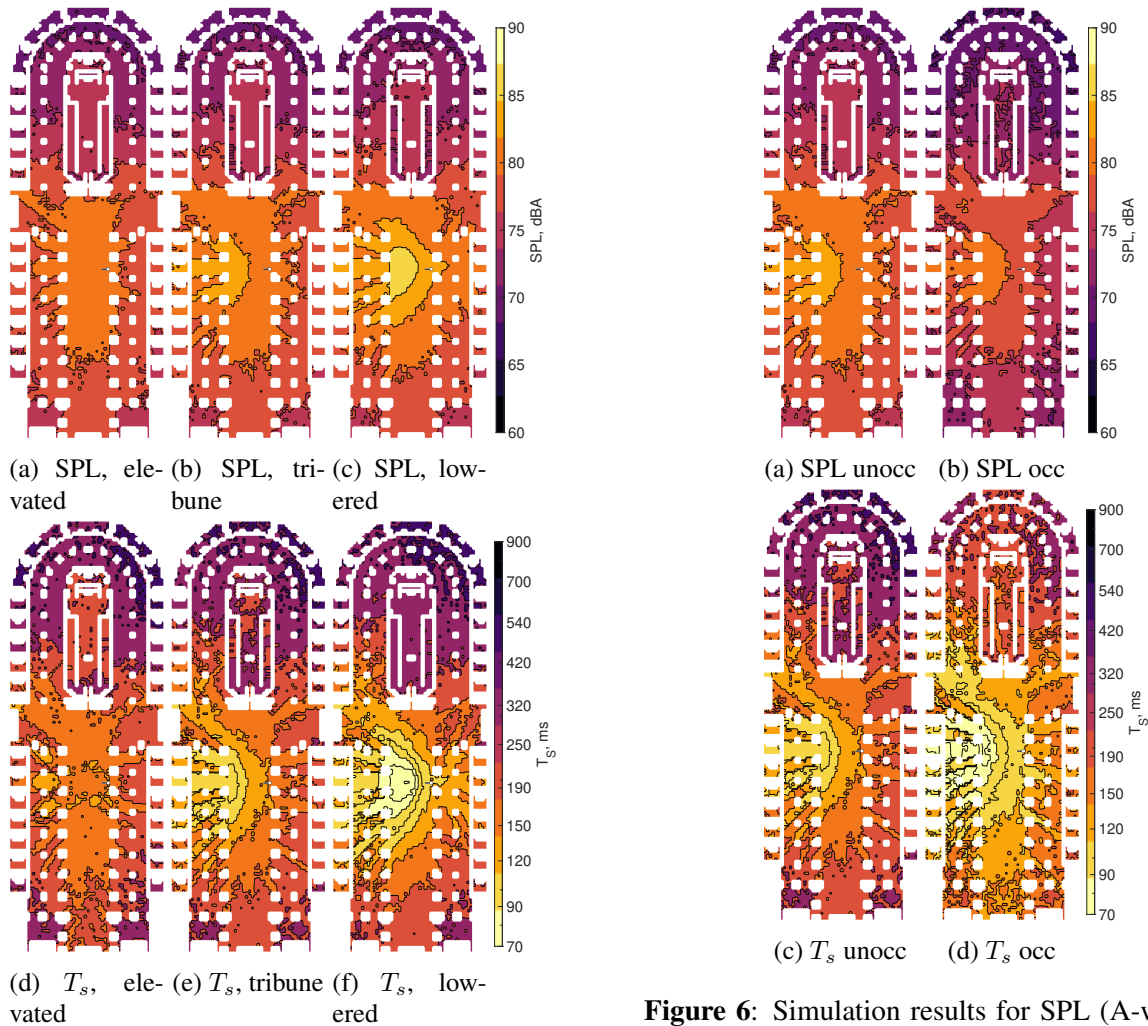


Figure 5: Simulation results for SPL (A-weighted) and Center time, unoccupied condition, organ position in the 2nd bay (C): organ height: elevated, tribune position, and lowered.

during festivals (see Section 2.1). Figure 7 shows the reverberation time in Notre-Dame averaged across receiver positions throughout the cathedral, comparing unoccupied and festival states. The SPL maps show a very similar pattern in both conditions, with the festival condition ≈ 3 dB quieter. Likewise, T_s decreases significantly with the reduced reverberation time.

(a) SPL unocc (b) SPL occ

(c) T_s unocc (d) T_s occ

Figure 6: Simulation results for SPL (A-weighted) and Center time for unoccupied and occupied conditions. Organ positioned in the 2nd bay.

3.4 Discussion

The location of the first medieval organ (second half of the 14th century) in the Cathédrale Notre-Dame de Paris is based on conjecture. Historical sources suggest that the instrument was positioned in the nave, not far from the liturgical choir, high up and in front of a window.

Simulations are employed to investigate the probable position of the 14th century instrument according to historical sources, with the help of a historically-informed 3D geometric model of the liturgical choir and the nave being furnished in the medieval style, with wooden stalls, tapestries, and a jubé and clôtüre enclosing the chancel.

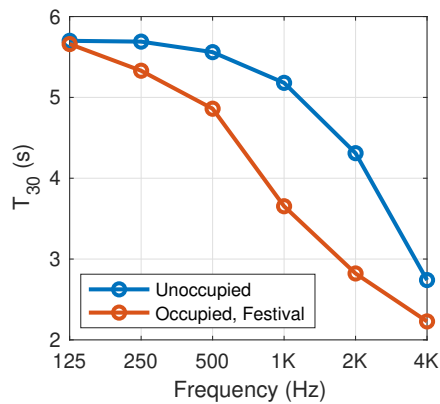


Figure 7: Reverberation time (T_{30}) of Notre-Dame in the 15th century for the unoccupied condition and the occupied condition including hypothetical festival decorations (e.g. textiles).

The instrument was almost certainly placed at the triforium level. This is the most convenient place for practical construction. The triforium level in Cathédrale Notre-Dame de Paris contains large tribunes where the bellows, activated by a wheeled machine, could easily have been installed. Acoustic simulations demonstrate lower perceived sound power and clarity for a more elevated position. This reinforces this hypothesis of a triforium-level swallow’s nest instrument.

The spatial effects of a position in the 5th bay and tribune are similar, privileging the center of the nave regarding sound power and clarity.

The displacement of the large organ from the southern wall to the western tribune offers more acoustical contrast with the 2nd bay position. Note that the western tribune organ offers the maximal contrast between music performed at the cathedral’s eastern (choir) and western (organ) sides. The western position would emphasize musical means the dialectics between choir and nave, clerics and lays, secular and mundane worlds inscribed in the geography of Île de la Cité in medieval Paris as well as in the mentality of the late middle ages.

In conclusion, acoustic evidence supports the hypothesis that the 14th century organ was installed in a swallow’s nest hanging from the 2nd bay at the tribune level.

4. FUNDING

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A. ARCHITECTURAL GLOSSARY

Ambulatory: The side aisles of the apse surrounding the choir, but separated from the choir by the clôture. This area was unconsecrated and not used by the chapter during services.

Apse: The semicircular termination of the cathedral to the east of the transept. In this paper, it sometimes used interchangeably with chancel.

Chancel: The portion of the eastern end of the cathedral containing straight bays, including the liturgical choir and portions of the ambulatory.

Choir/liturgical choir: The center portion of the apse containing the choir stalls and seats for high church officials.

Clerestory: The uppermost walls of the central aisle just below the ceiling, where the large stained glass are located.

Clôture: The highly decorated stone wall enclosing the choir and the sanctuary, separating them from the ambulatory.

Jubé: The rood screen built at the western end of the choir, separating the choir from the transept.

Nave: The straight, long, western portion of the cathedral, including both the central aisle and the two rows of side aisles. While this area was processed through during certain portions of the liturgy, it was an unconsecrated region of the cathedral and not the primary location of religious observances.

Sanctuary: The portion of the apse where the high altar is, separated by a low wall and some stairs from the choir.

Transept/transept crossing: The rectangular aisle dividing the main axis of Notre-Dame into nave and apse. The transept is responsible for the cruciform shape of the cathedral.

Triforium: The interior galleries along the perimeter of the cathedral, above the arcades of the ground floor and below the clerestory windows. The triforium includes both wide galleries (tribunes) along the perimeter of the nave and apse, and narrow service passages in the transept.