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Case study

# Intangible cultural heritage: The sound of the Romanesque cathedral of Santiago de Compostela

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ABSTRACT

Since the end of the twentieth century the increasing importance of cultural heritage has been complemented with the recognition and protection of intangible heritage. This new approach to cultural heritage requires scientific knowledge supported by new technologies. This context is used as the starting point for furthering knowledge of the relationship between architecture, liturgy and music in Romanesque church architecture – the first artistic style to become widespread in the West – by including a new intangible dimension: sound. This case study of the emblematic cathedral of Santiago de Compostela uses computer simulation to expose the acoustic behaviour of the original Romanesque space – now covered by Baroque elements – and its effect on the functional and spatial structure.



## 1. Research aim

The main aim of this work is to analyze the relationship between architecture, music and liturgy through the acoustics of the Romanesque cathedral of Santiago de Compostela, which is used for both religious worship and for the preservation of religious relics. This unique cathedral shows no physical traces of the mediaeval Roman liturgy or the Romanesque space, which have been concealed by Baroque interventions. However, it is possible to create an acoustic model of the original Romanesque space and use computer simulation to establish the main parameters that determine the acoustic behavior of this space. It is even possible to use auralizations to virtually recreate the sound of the Romanesque cathedral using "acoustic archaeology" [1]. This technology aims to recover one of the lost or forgotten intangible cultural heritage values of the cathedral of Santiago, that of sound, and help establish its status as a factor for cultural dynamization.

## 2. Introduction

The late eleventh century liturgical reformation and the increasing importance of religious orders under the hegemony of Cluny set the stage for the birth of Romanesque, the first artistic style to be widespread in the West. This new interpretation of space encouraged the extraordinary development of Christian music, both that of Gregorian chant and the birth of polyphony.

The study of Romanesque religious architecture should move away from traditional studies to concentrate on its physical reality, its visual and style variations, interpreting the building as a whole, thus opening up to new historical and heritage readings, to changes in its functional history [2] and to the incorporation of the liturgy [3] and music [4] as intangible values to be protected [5].

The organization and purpose of the liturgy and the development of music determined the configuration and evolution of Romanesque architecture. This close relationship between architecture, music and liturgy demanded a new approach that focuses on the multi-sensory experience of architecture, complementing the visual space with the sound field, and incorporating the acoustic dimension through the reconstruction of sound.

Specialist literature includes research with different approaches to this relationship, either through the analysis of the relationship between architecture and acoustics in religious buildings in their current condition [6,7] from the perspective of the acoustic evolution connecting liturgy, music and architecture [8–10], or through the acoustic study of these interconnections in the origins of Christianity with layouts which have clearly undergone transformation or may no longer exist [11].

The cathedral of Santiago de Compostela is an exceptional example as it has been a universal pilgrimage destination for Christians since the Middle Ages. The cathedral, along with the old town, was declared World Heritage Site by UNESCO in 1985, and the Way to Santiago, also declared a World Heritage Site in 1993, formed part

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of the most important mediaeval religious and cultural movement, the most efficient channel for the construction of Europe.

## 3. Methods

The latest techniques for acoustic prediction were applied once the acoustic models of the Romanesque cathedral had been constructed reproducing its geometry and the distribution of the sound absorption-dispersion of the materials had been established, and the receivers positioned according to occupation, sound source position and the different liturgical uses of each space.

The acoustic model simulations provided the room impulse responses (RIR) for each receiver, implementing high quality auralizations to generate all the information on the acoustic conditions of the room. Once RIRs were obtained it was possible to calculate the most important acoustic parameters of the Romanesque cathedral and generate audio signal samples that could be used for subjective valorisations or auralizations. This procedure is used for "acoustic archaeology", a virtual acoustic reconstruction of these spaces from the past, incorporating acoustic characteristics as an important part of their intangible heritage. The software used for the simulation was CATT-Acoustic, version 9.0, with TUCT (The Universal Cone Tracer) calculation engine version 1.0 [12].

This methodology aims to assess the differences in the acoustic behaviour of each spatial configuration according to purpose, instead of merely determining the acoustic quality of this space according to current room acoustic evaluation criteria.

### 3.1. Case study

The main documentary source for updating the image of the cathedral of Santiago to bring to life the festive, liturgical and musical representation at the time of consecration (1211) is the *Codex Calixtinus* [13]. This codex includes the liturgy and music produced to honor the apostle Santiago on major feasts. The Romanesque space is documented in research by K.J. Conant [14], and other research projects currently being carried out by Wunderwald and Rüffer [15] and Dagenais [16].

The Romanesque cathedral of Santiago de Compostela follows the model of "pilgrimage churches" of French origin, both in terms of style and the majority of its functions, and is one of the most beautiful typically Romanesque mediaeval churches. It was built mostly out of granite, with a Latin cross floorplan, and three side naves whose measurements are included in the Codex (Fig. 1). The main nave is covered by barrel vaults while the side naves are covered by ribbed vaults. The naves are separated by columns, with a tribune over the side naves covered by a quarter round barrel vault.

The formal plan is based on monastic buildings, from which its use is adapted, with a shallow presbytery for the main altar and a wide choir in the central nave for the chanting of divine office. This stone choir, executed by Master architect Mateo, follows the model of Cluny and was to become a permanent element in Spanish cathedrals. It is located in the first three stretches of the nave from the transept, with a fourth stretch assigned to the *leedoiro*, a high tribune used for sermons in ceremonies.

### 3.2. The acoustic model

The acoustic models used for the simulations with CATT-Acoustic had 5600 planes and a volume of 48,202 m$^3$. These simulations make it possible to ascertain how the sound field is modified by the mass presence of a congregation on major feasts. Three ominidirectional sources were placed at a height of 1.5 m above ground level, positioned according to the main liturgical functions of the cathedral: the presbytery for the celebration of the mass at the altar (S1), the choir for chanting by the canons (S2) and

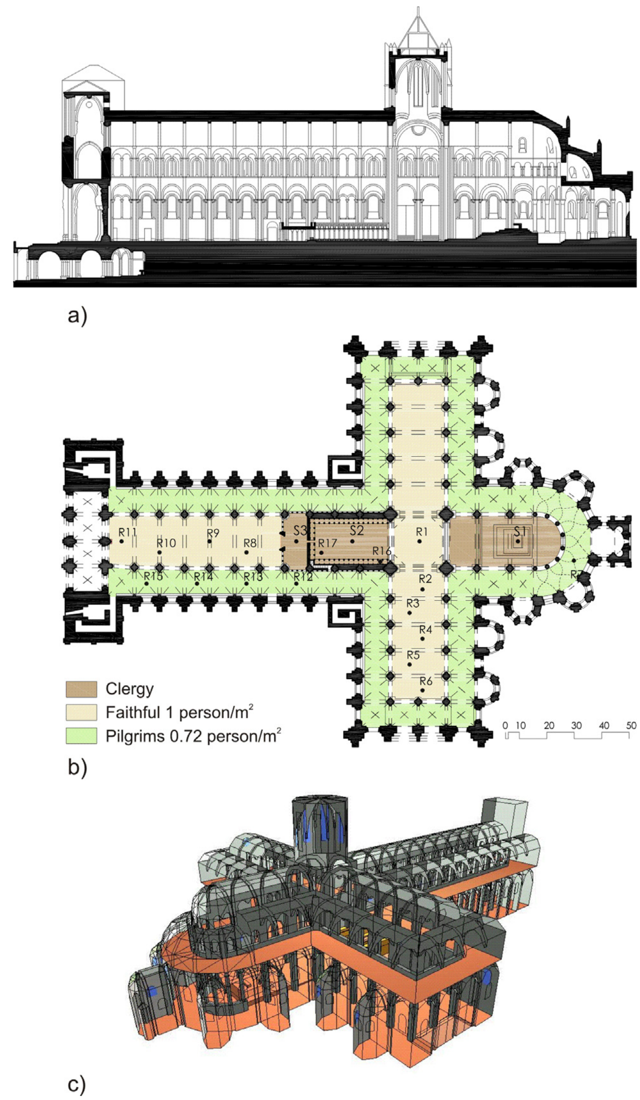


**Fig. 1.** (a) Longitudinal section and (b) floorplan of the Romanesque cathedral of Santiago de Compostela. Zoning and distribution of sound sources and receivers; (c) acoustic model.

the *leedoiro* for speech (S3). Twenty-one receiver positions were adopted (Fig. 1, Table 1) distributed throughout the transept, ambulatory, choir, *trascoro*, side naves and tribune, all at 1.60 meters from the ground, a height which has been set assuming that the congregation was standing. Each surface of the building was assigned a material with its corresponding absorption and scattering coefficient (Table 2), also incorporating the absorption of sound energy by the volume of air in this large space.

The results of the main acoustic parameters and the subjective perception defined in ISO 3382-1:2009 [17] were assessed following the simulation of the acoustic models generated. The physical

**Table 1**
Receiver location.

| Zones | Receivers |
|---|---|
| Transept | R1, R2, R3, R4, R5, R6 |
| Ambulatory | R7 |
| *Trascoro* | R8, R9, R10, R11 |
| Aisle | R12, R13, R14, R15 |
| Choir | R16, R17 |
| Tribune (first floor)[a] | R18, R19, R20, R21 |

[a] Placed above points 12 to 15 respectively.

**Table 2**
Absorption coefficients for materials used.

| Material | Surface (%) | 125 Hz | 250 Hz | 500 Hz | 1 kHz | 2 kHz | 4 kHz |
|---|---|---|---|---|---|---|---|
| Granite (floor[a], walls[a], choir[b]) | 61.1 | 0.02 | 0.02 | 0.03 | 0.04 | 0.05 | 0.05 |
| Plaster vaults[a] | 20.4 | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 | 0.05 |
| Windows[a] | 1.3 | 0.13 | 0.12 | 0.08 | 0.07 | 0.06 | 0.04 |
| Wood[a] | 3 | 0.09 | 0.09 | 0.08 | 0.08 | 0.10 | 0.07 |
| Audience[b] area, 1 person/m$^2$ | 2.5 | 0.16 | 0.29 | 0.55 | 0.80 | 0.92 | 0.90 |
| Audience[b] area, 0.72 person/m$^2$ | 11.7 | 0.10 | 0.20 | 0.41 | 0.65 | 0.75 | 0.71 |

[a] Scattering coefficients 0.12, 0.13, 0.14, 0.15, 0.16, 0.17.
[b] Scattering coefficients 0.55, 0.60, 0.65, 0.70, 0.75, 0.80.

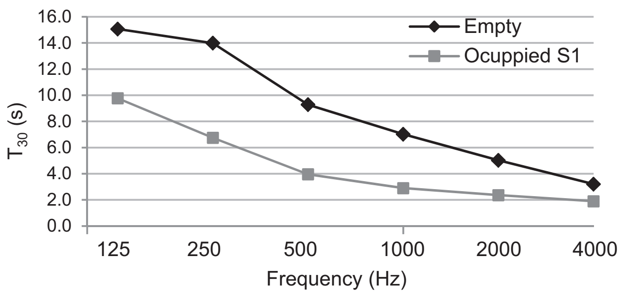


**Fig. 2.** Octave-band values of average reverberation time $T_{30}$: empty and occupied.

reverberation of the space was calculated through reverberation time ($T_{30}$). The perceived reverberation was correlated with Early Decay Time (EDT). The clarity perceived for music was related with clarity ($C_{80}$). The perceived sound level was assessed through sound strength (G) that measures the amplification capacity of the building, making it possible to assess the uniformity of the sound field. Finally, speech clarity was assessed using the definition parameter ($D_{50}$). All parameters were spectrally averaged following ISO 3382-1:2009.

## 4. Results

The indoor acoustic qualities of the Romanesque cathedral, with its enormous volume of 48202 m$^3$ and highly reflectant materials, encouraged high reverberation times with mid frequency values, $T_m$, of 8.15 s. The mass occupation of the cathedral in the transept

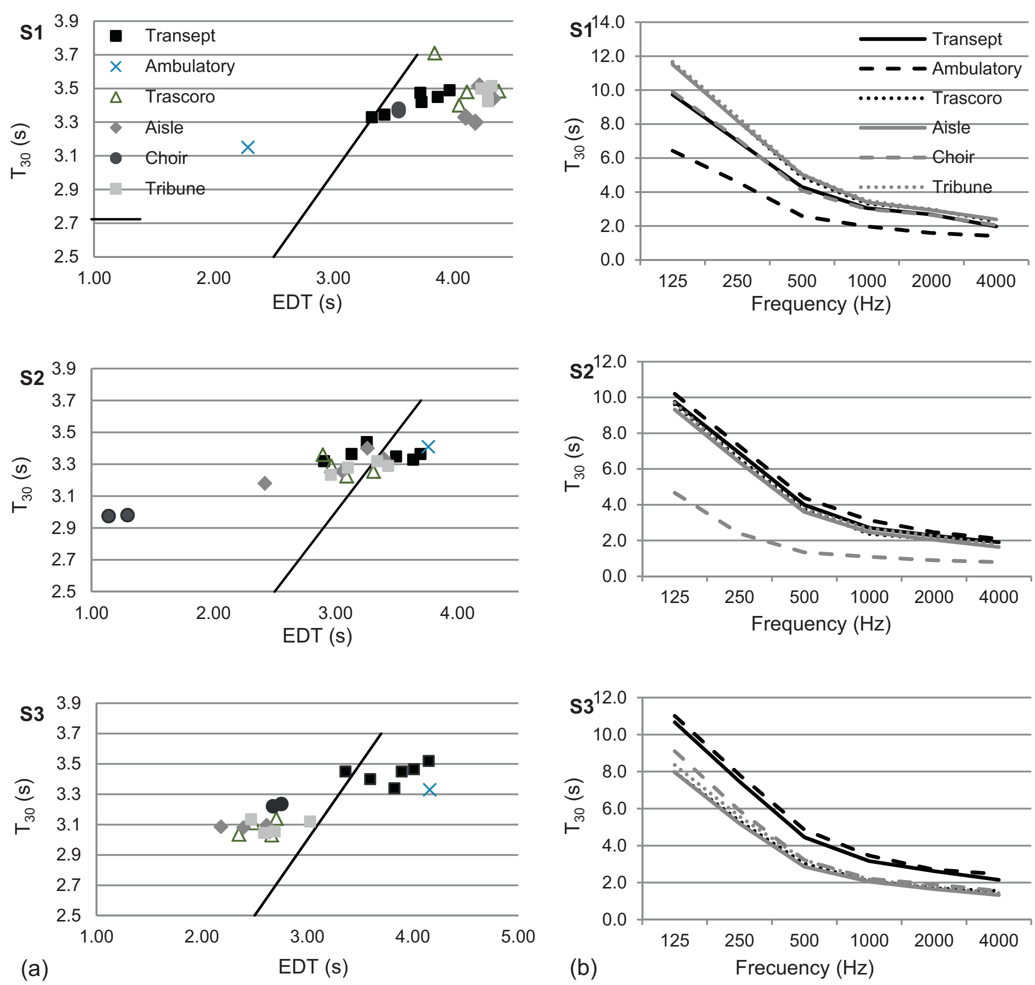


**Fig. 3.** (a) $T_{30}$/EDT by source and receiver. (b) Octave-band values of average reverberation time $T_{30}$ by zones and source.

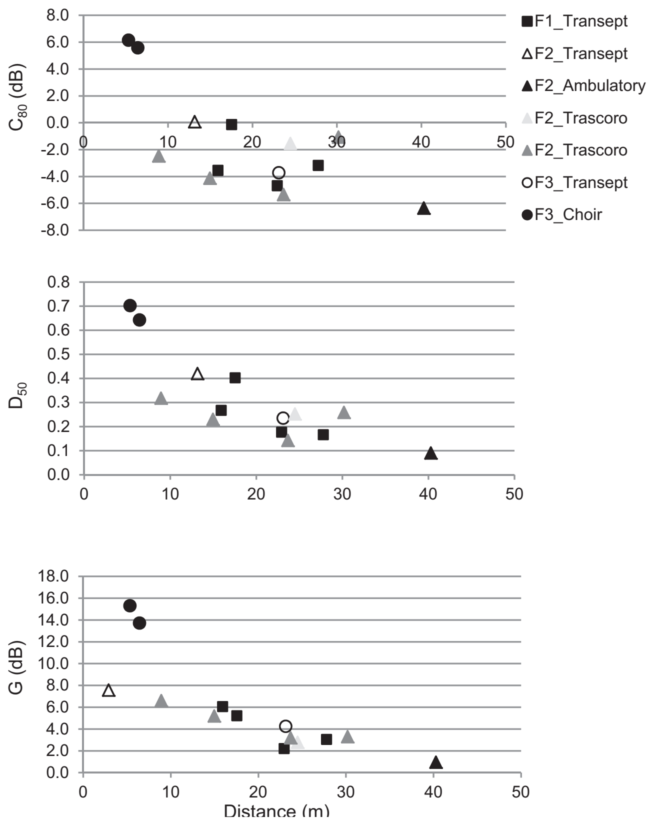


**Fig. 4.** Spectral behaviour and average values for acoustic parameters: clarity $C_{80}$, definition $D_{50}$ and sound strength G with respect to source-receiver distance for receivers with direct sound.

and *trascoro* during the liturgy on major feasts, as well as the pilgrims passing through unobtrusively visiting the apostle's relics in the side naves and tribunes, brought about a significant increase in sound absorption and a notable reduction in reverberation time, reaching $T_m$ values of 3.43 s (Fig. 2).

Although the physical reverberation of the space, $T_{30}$, was virtually independent from the position of the sound source, this was not the case with its EDT (Fig. 3). During liturgical celebrations in the presbytery, from the main altar (S1), EDT values for a cathedral full of the faithful were slightly higher than those of $T_{30}$, which indicated greater reverberation. During chanting from the choir (S2) reverberation varied greatly depending on receiver position. Thus, in the choir EDT values were very low, 1.20 seconds, suited to the responsorial psalmody which took place in it, while the average EDT values in the rest of spaces ranged from 3.00 to 3.35 s. Finally, two different types of behaviour were observed for liturgical readings to the faithful from the *leedoiro*. The areas of the *trascoro*, side naves, choir and tribunes showed averaged EDT values ranging from 2.45 to 2.70 s, in contrast with the areas further away, such as the transept and ambulatory, with greater EDT values and therefore greater reverberation. The considerable distances between source and receiver, combined with the lack of direct sound and early reflections were the causes of this increase in reverberation.

This clear spatial differentiation was complemented by energy parameters of clarity $C_{80}$ and definition $D_{50}$, along with sound strength G (Fig. 4):

- with the sound source (S1) placed on the main altar for mass, the absence of direct sound and early reflections in most areas, in conjunction with the large source-receiver distances, resulted in poor acoustic conditions for music, with $C_{80}$ values below −5 dB, except in areas close to the source: choir, ambulatory and transept. The same occurred with speech, with very low $D_{50}$ values, below 0.30. The transept area was occupied by the faithful, making them part of the liturgy being celebrated from the presbytery and the choir. Therefore this was a space for viewing both the offices and the relics, despite poor acoustic conditions, and the importance of speech was not so much in its content but in vocal variations, within an interpretation of the liturgy transformed into a theatrical representation;
- the position of the sound source in the choir (S2) was quite different from the perspective of acoustic conditions. The enclosed space of the choir provided adequate clarity $C_{80}$ and ideal $D_{50}$ values for choral singing, allowing for the addition of different voices and the development of polyphony. The wide stone choir could house the 72 Chapter members, increasing the number of simultaneous sound sources in choral masses. Thanks to the amplifying effects of this closed space, their voices were projected with a high strength in the cathedral. However, in the remaining areas of the cathedral this choral singing produced sound with high reverberation but little intelligibility ($D_{50}$ below 0.30), which was partially corrected by the melismatic and syllabic interpretation of Gregorian chant. The perception of the sound level was lower (G between −2 and 2 dB), producing the sensation of distant, yet well mixed, sound with no clear directionality;
- the position of the choir in the middle of the central nave generated a space behind it, the *trascoro*, an area that connected the faithful to the rite through readings and sermons from the *leedoiro* (S3). The high position and the reduction of the source-receiver distance barely improved speech intelligibility. The use of cantillation, the chanting of text at a slow rhythm, emphasizing stress and punctuation, improved intelligibility by adjusting the sound to the reverberation time, since the conditions in the *trascoro* were suited to chant, as can be deduced from the values for $C_{80}$.

The pilgrims walked through the side naves and tribunes seeing fragments of the liturgy, and receiving weakened sound from the different foci of celebration, with little clarity ($C_{80}$ outside the range ± 5 dB), and poor intelligibility ($D_{50}$ below 0.10), acoustics that were characteristic of a late reverberant field. However, pilgrims interacted acoustically with the space, providing sound absorption, joining in with the liturgical chants of the clergy and providing responses to the verses of some of the musical pieces, such as the *Dum Paterfamilias*, as featured in the Codex. The mass participation of the pilgrims transformed the Romanesque cathedral of Santiago into a large sound field.

Thanks to the new technologies used for the simulation of the acoustic model, auralization allows us to reproduce what the sound perceived by a listener in a specific point of the Romanesque cathedral would be, assuming a sound source emitting from another point of the cathedral. In addition, auralization makes it possible to carry out a subjective evaluation that can be compared with objective values. This will be dealt with in future studies. Two additional audio files are included, assuming the hypotheses of the cathedral when empty and occupied, for the assessment of the influence of the faithful and pilgrims on the acoustic behaviour of the Romanesque cathedral of Santiago. In both cases the sound source was located in the choir (S2) and the receiver in R4 (S2_R4_empty.wav and S2_R4_occupied.wav). The audio file is the result of the convolution of an anechoic recording with binaural simulated responses, processed with Multivolver software, a tool supplementing CATT-Acoustic. This anechoic signal consisted of a fragment of the piece Almighty and Everlasting God, by Orlando Gibbons [18].

## 5. Conclusions

The layout of the Romanesque cathedral of Santiago de Compostela was that of a complex organism with different interrelated parts functioning as an enclosed space with two clear functions: as a church for the faithful and the clergy, with a dual celebration of the Eucharist in the altar and choir; and the worship of the relics of the apostles, processing through the side naves and tribunes. This analysis of the acoustic dimension through the reconstruction of its sound adds to the knowledge of its intangible heritage value.

The high reverberation time in the empty church, calculated at mid frequencies as 8.15 s, was reduced to 3.43 s, thanks to the sound absorption of the faithful when it was occupied. The lack of direct sound and nearby early reflections in many parts of the cathedral, added to the presence in many areas of source-receiver distances over 20–25 m, caused a major loss in speech intelligibility and musical clarity.

The central position of the choir, in architectural and liturgical terms, had a major repercussion on the acoustic behaviour of the whole. An *ecclesiola in ecclesia* was created, a church for the clergy (actors) within a church for the faithful (spectators), a double function merging in a single space. With this layout the sound from the choir space could be heard throughout the nave, and its multiple reflections permeated the remaining spaces. The faithful identified this central space for liturgical celebration through the reverberation of sounds with no directionality, given that it was impossible to see the liturgy and the lack of direct sound made it hard to locate the source. The reverberation of sound made the visual experience recognizable, enriching it.

The space was configured as a liturgical space for music, with acoustic conditions suited to the modulated Gregorian chant and the chanted liturgy that was not focused on the intelligibility of the oral message but on the sensorial perception of reverberation. The interior reflecting space and its great volume expressed the divine presence through the multi-sensory experience, sound reflections, the mysterious power of being heard without being seen, with a sound that seemingly came from everywhere, blending the voices of the singers with angelic voices from heaven, as described in book IV of the Codex.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.culher.2014.05.008.

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