euronoise 2021
25th to 27th of October
Madeira, Portugal - online

Digital Recontruction of a Baroque Soundscape: The church of Sant'Ignazio di Loyola (1626), Rome

Barbe Dumoulin[1], Yannick Sluyts[2], Prof. Krista De Jonge[3], Prof. Monika Rychtáriková[4],

[1]KU Leuven, Department of Architecture, barbe.dumoulin@gmail.com
[2]KU Leuven, Faculty of Architecture, Belgium, yannick.sluyts@kuleuven.be
[3]KU Leuven, Department of Architecture, krista.dejonge@kuleuven.be
[4]KU Leuven, Faculty of Architecture, Belgium, monika.rychtarikova@kuleuven.be

Abstract
In this paper the soundscape of the Sant'Ignazio di Loyola was reconstructed to investigate the impact of different configurations on the speech intelligibility of Jesuit preachers. Using state-of-the-art geometrical acoustics simulation software, the acoustics of the church were simulated. The virtual model was calibrated using impulse response measurements performed in different parts of the church. This calibrated model was consequently used to check the influence of a pulpit and the possible addition of a dome to the church. The speech intelligibility of these different configurations was assessed using modern parameters such as C_{50}, D_{50} and STI. The speech modulation frequency of Christian preachers' speech is often lower than normal speech, indicating that the widely used STI parameter might underestimate speech intelligibility in churches. Auralisations were performed to subjectively test this hypothesis with different configurations.

Keywords: speech intelligibility, sacral architecture, pulpit, soundscape, auralisation

1 Introduction

The church of Sant'Ignazio di Loyola is a church of the Society of Jesus, a religious order of the catholic church. The Society of Jesus is a progressive movement that was born in the days of the Council of Trent and the Counter Reformation. This Counter Reformation was the start of an immense change in the use, liturgy, architecture and music of the churches. Intelligibility of speech was an important quality of the new churches, since preaching in a vernacular language became a standard practice in church. The pulpit increased in popularity during that time [1, 2].
The focus of the acoustical analysis was on the speech intelligibility inside the church since preaching in a vernacular language was the main and most important practice of the Jesuits. Different cases are interesting to investigate and compare. Firstly, it is interesting, architectural speaking, to test if the completion of the large dome would have made a significant difference on the acoustical parameters of the church. The same can be said for the possible addition of tapestries all over the church, since this could change the absorption coefficient of the church drastically. Finally and most important, it is checked what effect the pulpit had on the intelligibility of speech of the priest preaching from it.

2 The church of Sant'Ignazio di Loyola

The Jesuits had a general architect for all of their buildings around the world: Giovanni Tristano. The most important thing was the practicality of the buildings. They did not talk about form or style, but of functionality. The buildings had to fit the purpose for which they were built. Tristano produced a certain 'standardized' type of church that could be found in Rome and other countries. The church is a place where the liturgy and the speech can be practiced and heard by a big public. It is a big open space with a shallow apsis in the east. There are no more side aisles, only side chapels. A short Latin cross [3, 4].
The church of Sant'Ignazio di Loyola embodies an incredible spaciousness and grandeur with all its shapes, marbles and colours. It was designed by Orazio Grassi and built between 1626 and 1685. It was planned to build a large dome on top of the crossing. Due to technical and financial problems in 1677 the dome could not be completed. Instead, a canvas picture, on which there is a perspective painted by Andrea Pozzo, is used to close the dome opening in 1685 [5]. There surely used to be a pulpit present in the church, since preaching was the most important practice of the Jesuits. Nowadays there is no pulpit present. The pulpit would probably have resembled the one that is still present in the mother church, the church of Gesù. The church of Sant'Ignazio was based on this church. This pulpit is constructed against a pillar of the nave. Another source, a picture of 1930 shows a more modern pulpit [6]. This pulpit was freestanding more to the front of the church, in the crossing. Later this pulpit was also removed. Several sources prove that the church used to be decorated with tapestries all over the nave, crossing and choir during large religious or civil celebrations. One tapestry is still present in the church. Many hooks and rings present in the church suggest the use of tapestries.

3 Model of the church

A 3D model of the church is necessary to calculate and simulate different acoustic characteristics of the church and to make an auralisation. The model is made in SketchUp because it is compatible with Odeon. Odeon is a software used for simulating and measuring room acoustics. When a 3D model and surface properties are imported into Odeon, it is possible to predict, illustrate and listen to the acoustics. The model has to be watertight and it is important that details smaller than 10 cm are not drawn. These small details could lead to false results and long computation times. Moreover, very detailed models don't show improvements in accuracy. Rich decorated elements should be drawn as flat planes and can later be simulated correctly in Odeon with the proper absorption and scattering coefficients. The goal is to create an acoustically accurate model, not an architecturally accurate one [7, 8].

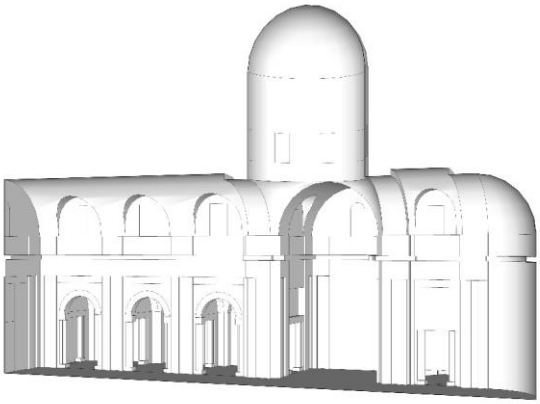

Figure 1 – The model of the church with dome

4 Calibration of the model

Acoustical measurements done in the church were used to rightly calibrate the model. Prof. em. Dr. J. P. Fricke and Tonmeister W. Voigt of the University of Cologne performed room acoustic impulse measurements in ten churches in Rome in 1976 [9]. The church of Sant'Ignazio di Loyola was one of them. The impulse response was measured by making use of gunshots. Several combinations were made with the different sources and receivers. The tests were performed in an empty church. The same conditions were applied to a model of the church. The results of the simulations in Odeon were compared with the results of the measurements in 1976. The EDT was compared. The absorption coefficients of the materials with the largest surfaces were adjusted per octave band to get as close as possible to the values of the measurements of 1976. This is an iterative process. A result was considered satisfying when the difference between the EDT of the simulation and the EDT of the measurements of 1976 is less than half a second. This tolerance is acceptable given the very long decay in the large volume.

5 Simulations

5.1 The effect of the dome

To test the influence of the dome on the speech intelligibility in the church, it is most important to look at the difference in reverberation time (T_{30}). The completion of the dome would have changed the volume of the church and the absorption coefficient. The volume would have increased by six percent.
Volume of the church without dome = 59.901 m²; Volume of the church with dome = 63.859 m².
It is assumed that the dome would have been made out of marble and plaster. These two materials have much lower absorption coefficients than the oil on canvas painting now covering the opening of the dome. It is expected that the addition of the dome would make the reverberation time longer. The dome would have been made out of hard materials compared to the painting covering the dome opening. The T_{30} of a model without dome is compared with a model with dome. On the graph the just noticeable difference (JND) relative to the results of the model without dome is also displayed.

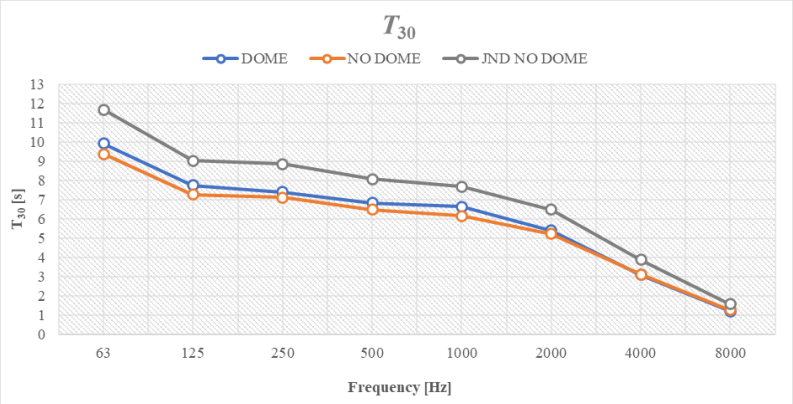

Figure 2 – T_{30} of the model with or without dome

There is a small difference in T_{30}, but this will not be noticeable. The reverberation time is slightly longer for the church with dome, as expected. For the other parameters, C_{50}, D_{50} and STI, there is as good as no difference visible. The completion of the dome would not have had any influence on the speech intelligibility of a priest preaching to a large audience from the nave or the crossing.

5.2 The influence of the tapestries

The addition of tapestries all over the nave, transept and choir will change the absorption coefficient of the church. The absorption coefficient of the tapestries is a lot higher than marble. It is expected that this will lower the reverberation time. To check the difference it is useful to compare the difference in T_{30} of the model without tapestries with one with tapestries. The influence of the tapestries might be small because the surface of these tapestries is small in comparison to the large church.

Total surface of the church = 18.279 m²
Surface of the tapestries = 204,3 m²
Percentage of the surface of the tapestries compared to the total surface of the church = 1,1%

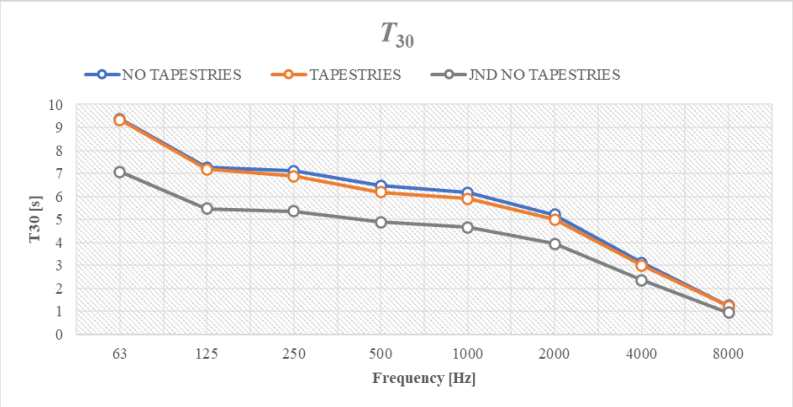

Figure 3 – T_{30} of the model with or without tapestries

As expected the reverberation time of the church with the tapestries is slightly lower. Nevertheless, the difference will not be noticeable. It can be concluded that the addition of tapestries at the observed positions had no perceivable effect on the reverberation time. Many more tapestries and soft materials should be present in the church for there to be a noticeable effect.

5.3 The influence of the pulpit

5.3.1 The influence of the location of the pulpit

In the history of the church there are several sources that give us information about the pulpit of the church. The first pulpit would probably have been located at one of the sides of the nave, as it is done in the mother church of the Jesuits, the church of Gesù. Later the pulpit was replaced with a more modern pulpit and moved to one of the sides of the crossing. To test what difference the location of the pulpit makes, the grid response of three cases is compared; the priest preaching from the nave without a pulpit (NP); the priest preaching from a pulpit in the nave (N); the priest preaching from a pulpit in the crossing (C). The reverberation time will be the same for all three cases, it is more useful to look at the differences in C_{50}, D_{50} and STI. On all the graphs the JND relative to the results of the model without a pulpit are displayed.

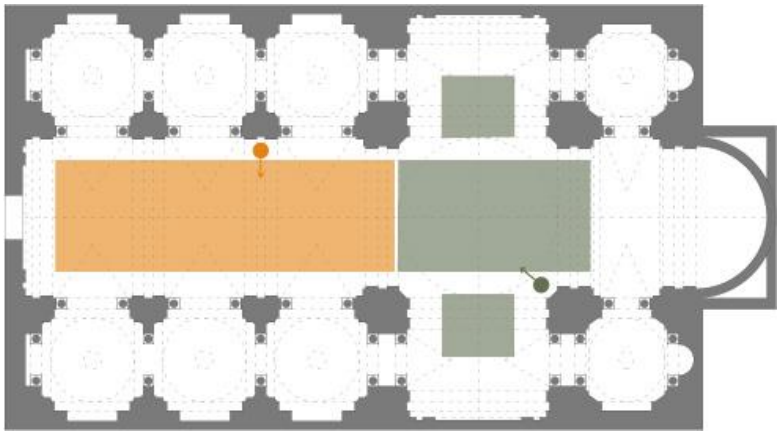

Figure 4 – Locations of the pulpit

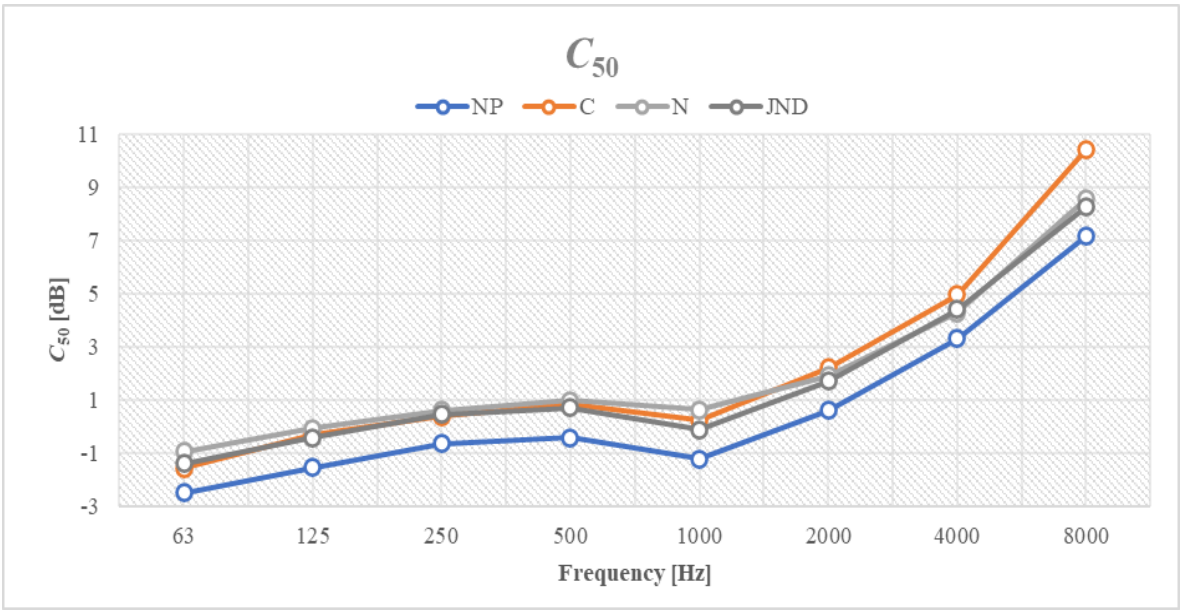

Figure 5 – C_{50} of the model without the pulpit, with the pulpit in the nave and with the pulpit in the crossing

The average values of all the parameters of the model with the pulpit in the nave and the model with the pulpit in the crossing are similar. Both cases perform better than the case without pulpit. The use of the pulpit will make a noticeable difference. If there is a pulpit used, it doesn't matter where this pulpit is located in the church, since the average values for the case with the pulpit in the nave are similar to the average values of the case with the pulpit in the crossing.

5.3.2 The influence of the location of the receivers

The pulpit is provided with a soundboard on top. This will ensure that more sound waves are reflected in the direction of the audience listening to the preacher in front of the pulpit. It is visible on the grid response that a larger area of the church will have good values for the acoustical parameters for speech intelligibility. It is interesting to evaluate how far the effect of the pulpit reaches and what difference the distance relative to the preacher makes. Five different receivers in the nave are compared in the model with the pulpit (P) and the model without the pulpit (NP).

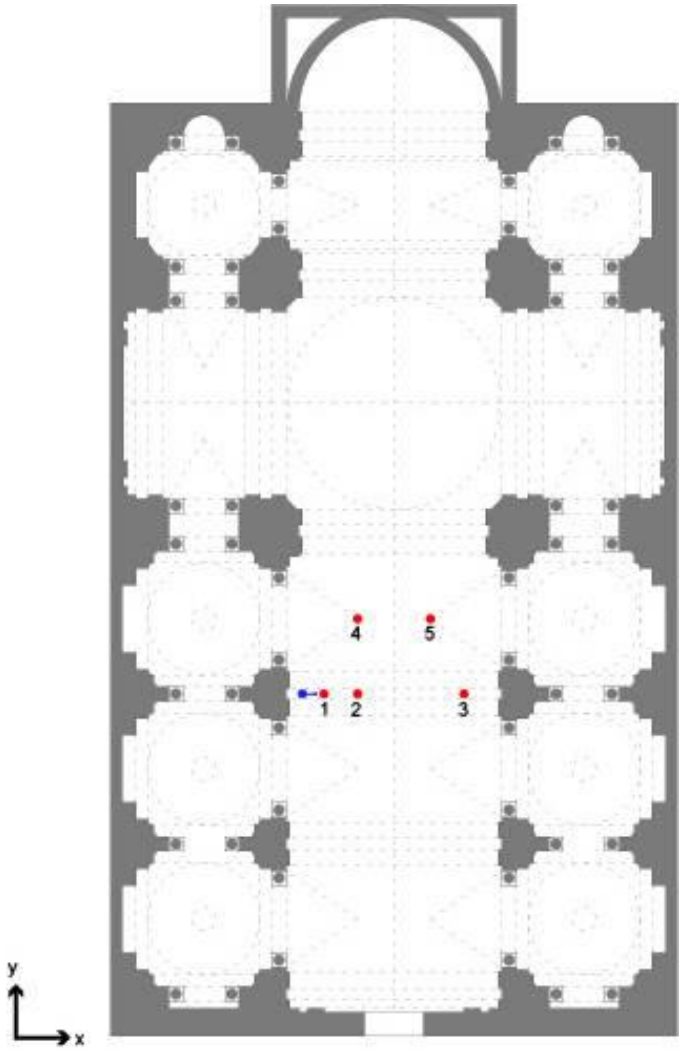

Figure 6 – Positions of the five receivers in the nave

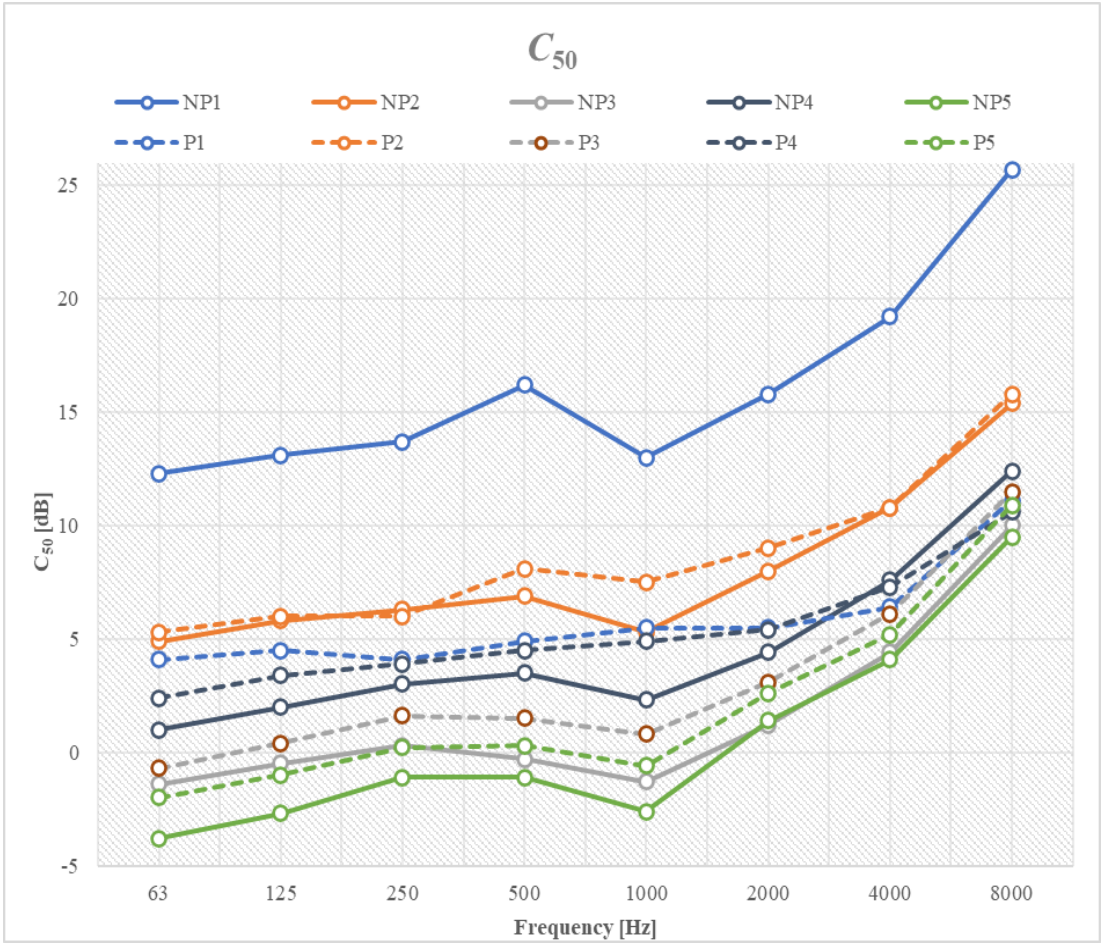

Figure 7 – C_{50} of the five receivers of the model without and with the pulpit in the nave

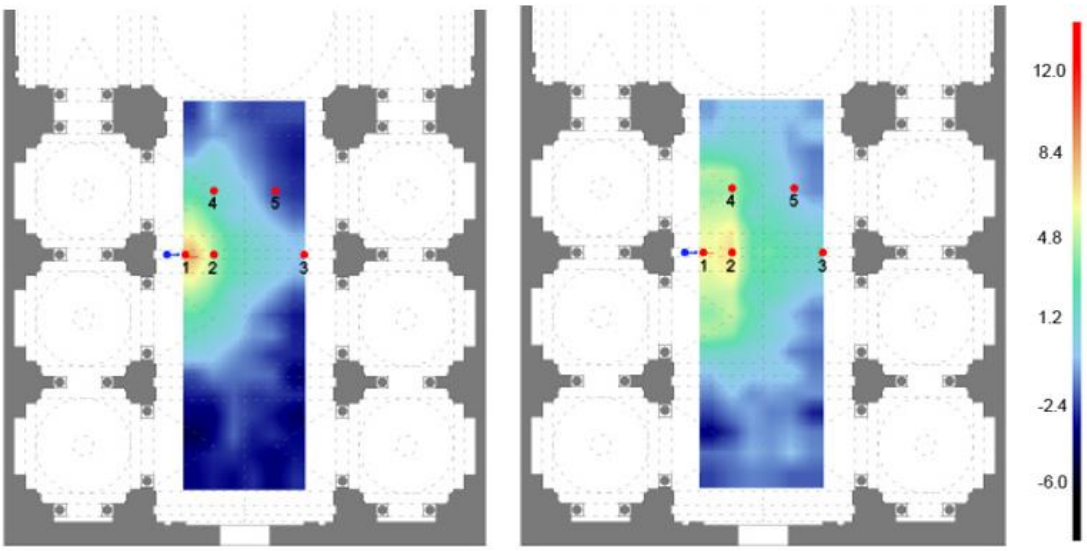

Figure 8 – C_{50} [dB] of the five receivers of the model without (left) and with the pulpit in the nave (right)

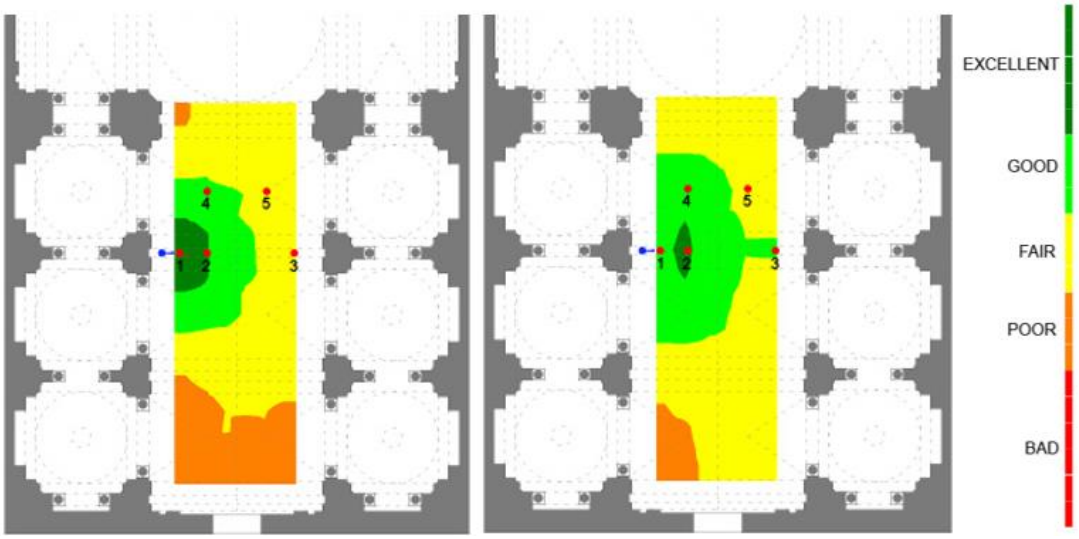

Figure 9 – STI of the five receivers of the model the without (left) and with the pulpit in the nave (right)

Looking at the average values, the case with the pulpit will be more advantageous for the speech intelligibility overall. When looking at different receivers at certain positions relative to the preacher, some other conclusions can be made. It is remarkable that the speech intelligibility at position 1 is better when the priest is not preaching from the pulpit. A bit further at position 2, the speech intelligibility will be similar in both cases when looking at the average values, but at the octave bands of 500 Hz and 1000 Hz there is a peak of the curves of the case with the pulpit. These are important frequencies for speech intelligibility. Therefore, the introduction of the pulpit will have a positive impact on the speech intelligibility of the preacher. This might be explained by the height at which the priest is located. When the priest is preaching from the pulpit, he is about three meters higher than the receivers. The other receivers at positions 3, 4 and 5 show similar results. There the pulpit does make a positive difference. The priest will be more intelligible preaching from the pulpit when the receivers stand at a certain distance or not in the direction in which the priest is preaching.

6 Auralisation

It is possible to listen to an audio file played in an acoustical simulated space. This can be an orchestra, speech or any other audio file of a sound. This way it is possible to get an idea of how this sound would be perceived in this acoustical simulated space. This is called “an auralisation”.
An anechoic audio file is played in a room with a measured or simulated impulse response. An anechoic audio file is an audio file that is recorded in a fully absorbing chamber, an anechoic chamber. This way there is no reflection of the recorded sound, meaning the reverberation time is close to zero. When this audio file is afterwards played in the simulated room, it is possible to hear how the sound of the audio file will be reflected in the room, depending on the volume, shape and materials of the room [10].
In this case it is interesting to listen how the priest would have been perceived in the different cases and at the different locations. This auralisation makes it possible to hear how big of a difference the pulpit really makes and how much the distance from the preacher matters. It is hard to notice a difference in the introduction of the pulpit at positions 3, 4 and 5. At positions 1 and 2 this is much easier. The distance from the preacher is also very noticeable.

7 Conclusions

After correctly calibrating the model of the church in Odeon, it was possible to simulate and compare different relevant cases. For this subject, the church of Sant'Ignazio di Loyola, the speech intelligibility played a huge role in the usage of the church. This was therefore the main focus of this research.
An important historical event was the fact that the dome could not be built due to financial and technical problems. A model with and without the dome was acoustically analysed. A surprising result was obtained. Since the dome would have changed the volume and the absorption coefficients of the church significantly, it was expected that the reverberation time of the church would be longer if the dome were to be built. This was not the case. The dome had no noticeable influence on the relevant parameters for speech intelligibility. This can be explained by the fact that the church has such a large and high volume. The distance between the preacher and the dome is about 30 meters. The influence of the dome does not reach that far.
A similar conclusion can be made for the addition of tapestries to the nave, transept and choir. The surface area of the tapestries is so small in comparison to the total surface area of the church, that this barely has an influence on the acoustical parameters. Many more tapestries and soft materials should be present in the church for there to be a noticeable effect.
A relatively small element like the pulpit on the other hand, does have a significant influence on the speech intelligibility. This is because the pulpit has a direct influence on the sound waves emitted by the preacher. The pulpit makes sure that more sound waves are reflected in the direction of the receiver and this is noticeable in the results of the simulations. The effect of the pulpit is more significant the closer a receiver is located to the pulpit. At the closest position near the pulpit the influence will not be positive since the priest preaching from the pulpit is located at a higher position than the receiver. The acoustical parameters show that it did not matter where the pulpit was located in the church. Thanks to the acoustic software and the simulations it is also possible to define the influence of the distance in between the receivers and the preacher.
The auralisation confirms the conclusions that were made after the simulations. The influence of the pulpit can be clearly heard at the positions closer to the preacher. Further away from the pulpit it is more difficult to hear a difference. The values of the acoustical parameters at these positions only show a small noticeable difference.
To conclude, this research has proven that speech intelligibility was not influenced by the decision to not built the dome or the presumable addition of tapestries during festivities. The pulpit however has a positive effect on the speech intelligibility. The priest could reach a larger crowd inside the church.

Acknowledgements

A special thanks goes to Prof. em. Dr. J. P. Fricke and Mr. Lorenz-Kierakiewitz for providing the impulse responses measured in the church of Sant'Ignazio di Loyola in 1976. These results were very useful in the process of this research.

References

[1] John W. O'Malley, The First Jesuits, London, Harvard University Press, 1993

[2] Jaime Navarro; Juan J. Sendra; Salvador Muñoz, The Western Latin church as a place for music and preaching: An acoustic assessment, Elsevier Ltd., 2008

[3] John W. O'Malley, Gauvin Alexander Bailey, Steven J. Harris, T. Frank Kennedy, The Jesuits: Cultures, Sciences, and the Arts 1540-1773, Toronto, University of Toronto Press, 2000

[4] Pietro Pirri S. J., Giovanni Tristano e i primordi della architettura gesuitica, Institutum Historicum S. I., 1955

[5] Giovanni Martinetti, Sant'Ignazio, Rome, Marietti, 1967

[6] Ralph Deakin, RIBA: https://www.ribapix.com/Church-of-SantIgnazio-di-Loyola-Campo-Martio-Rome-the-apse-and-high-altar-with-frescoed-ceilings-executed-by-Andrea-Pozzo_RIBA27872# (accessed on 12/07/21)

[7] Lidia Alvarez-Morales, Francesco Martellotta, A geometrical acoustic simulation of the effect of occupancy and source position in historical churches, Elsevier, 2014

[8] Sebastian Duran, Martyn Chambers, Ioannis Kanellopoulos, An archaeoacoustics Analysis of Cistercian Architecture: the Case of the Beaulieu Abbey, Basel, Switzerland, MDPI, 2021

[9] Klaus-H. Lorenz-Kierakiewits, Prof. Em. Dr. Jobst Fricke, Room Impulse Response Measurements in Ten Churches of Rome: Hörsamkeit, Intelligibility and Possible Suitable Positions for Performances of Church Music, Cologne, Germany, University of Cologne, 2013

[10] Auralisation, Odeon: https://odeon.dk/learn/articles/auralisation/ (accessed 04/06/21)