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Virtual acoustic reconstruction of the Miners' Theatre in Idrija (Slovenia)

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ABSTRACT

This study reports history and the original architectural design of the Miners' Theatre in Idrija. This theatre is usually considered to be the oldest such building in Slovenia and in 2001 it was declared a cultural monument of national importance. The building shape was typical of numerous small stand-alone theatres throughout Central Europe in the 18th century. The original design was later changed several times until it has reached the actual aspect. To analyse the acoustic characteristics of the current room (often named "Film Theatre"), an acoustic survey was carried out and several acoustic parameters defined in the ISO 3382-1 standard, were calculated and analysed. To study the acoustic characteristics of the theatre in its original shape, a numerical model was realized and properly validated. The simulations of three different scenarios were performed and the results obtained from the simulation have been analysed and commented.

1. Introduction

The study of the acoustic characteristics of historical theatre has received considerable attention in the last two decades, with a number of researchers focussing on this topic and the acknowledgement of acoustics as intangible cultural heritage [1–5].

To obtain a complete description of spatial sound propagation in these historical places, acoustic impulse responses are measured by setting sound sources and receivers in some relevant positions [6,7], including the effects of resonant wood [8], and extracting the room parameters.

Unfortunately, a lot of historical theatres were damaged or destroyed during past wars, natural disasters or fires so survived ancient theatres need periodic refurbishments [9–11]. Moreover, intensive usage, loss of the original function, and previous uncontrolled restorations are often causes of damage to this cultural heritage, which often appears significantly different from the original structure as well as from the original acoustics [12], causing a different psychoacoustic impression [13].

This paper focuses on a small theatre, actually known as "Film Theatre" but in the past as "Miners' Theatre". Miners' Theatre is usually considered to be the oldest such building in Slovenia and in 2001 it was declared a cultural monument of national importance, but the original design was later changed several times until it has reached the actual aspect, as auditorium and cinema. So, the present work aims to analyse the acoustics of Miners' Theatre in its supposed original state by using the virtual simulation of the different configurations. It could be useful to better understand how the audience attended the performances in this small theatre during the 18th century. Furthermore, another aspect that can be pointed out through virtual simulation is the effect of occupancy and sceneries in small places. Indeed, this issue often constitutes a challenge during onsite measurements, mostly because of the difficulty of performing measurements in occupied conditions, combined also with the even most difficult task of filling the theatre with a sufficiently large number of persons.

Moreover, today theatres, auditoria, and cinemas have been returned to be the centre of cultural activities and are used for different kinds of events like music performances, concerts, drama and conferences. Nevertheless, many performances do not achieve the success of the critics and the audience due to the weak acoustics.

To get good acoustics in an auditorium is necessary that the sound is strong enough that the simultaneous components of a complex sound maintain an appropriate ratio between their intensities and that the following sounds, whether it is speech or music, are clear and distinct, free from overlapping and without external noise. This means that the sound maintains its original characteristics until the listeners, even enriched by the acoustics of the room. In this work acoustic characteristics were measured in the restored Film Theatre, besides it was reconstructed the model of the ancient Idrija Miner's Theatre to discuss its original acoustics

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and provide some suggestions for its future renovation and use. The reconstruction was developed considering the material provided the Municipality of Idrija,

2. The case study: Idrija Theatre

Idrija is a lovely little town located in western Slovenia. The village belongs to the Inner Cariola region and hosts the second largest mercury mine in the world, and consequently the village hosts stores and infrastructure, as well as miners' living quarters. Perhaps the most important historical building in Idrija is the Miners' theatre. The theatre, which is considered to be the oldest such building in Slovenia, was built around 1770 and is closely connected with the development of the mercury mine in the town. The theatre was located in the centre of the town, near several other new buildings constructed around at the same time. Thus, the theatre was a part of a rather ambitiously conceived urbanisation of the settlement and illustrates the way of life in it in the late Baroque period.

The construction of the theatre was financed from voluntary contributions by miner employees. In the beginning, the theatre was opened for only three performances a year, on the Emperor's birthday, on the patron saint of Idrija miners, St. Acacius (22 June), and on another patron saint of miners, St. Barbara (4 December).

The building had the typical shape of numerous small stand-alone theatres throughout Central Europe in the 18th century: longitudinal ground plan with a semi-circular space for the audience, surrounded by boxes and sufficiently spacious stage section [14–16].

The original structure, which was later changed many times, can be reconstructed in particular thanks to historical plans dated back from 1882. The theatre measured 27 m in length and 12.5 m in width externally. The rectangular stage area measured 8 by 11 m and was located in the eastern part of the building. An actor could access to the stage area from the stalls via two wooden staircases. The theatre could hold about 300 and 400 people.

The hall with seats sloped gradually towards the stage, ending in space for performers. The stalls area was surrounded by 17

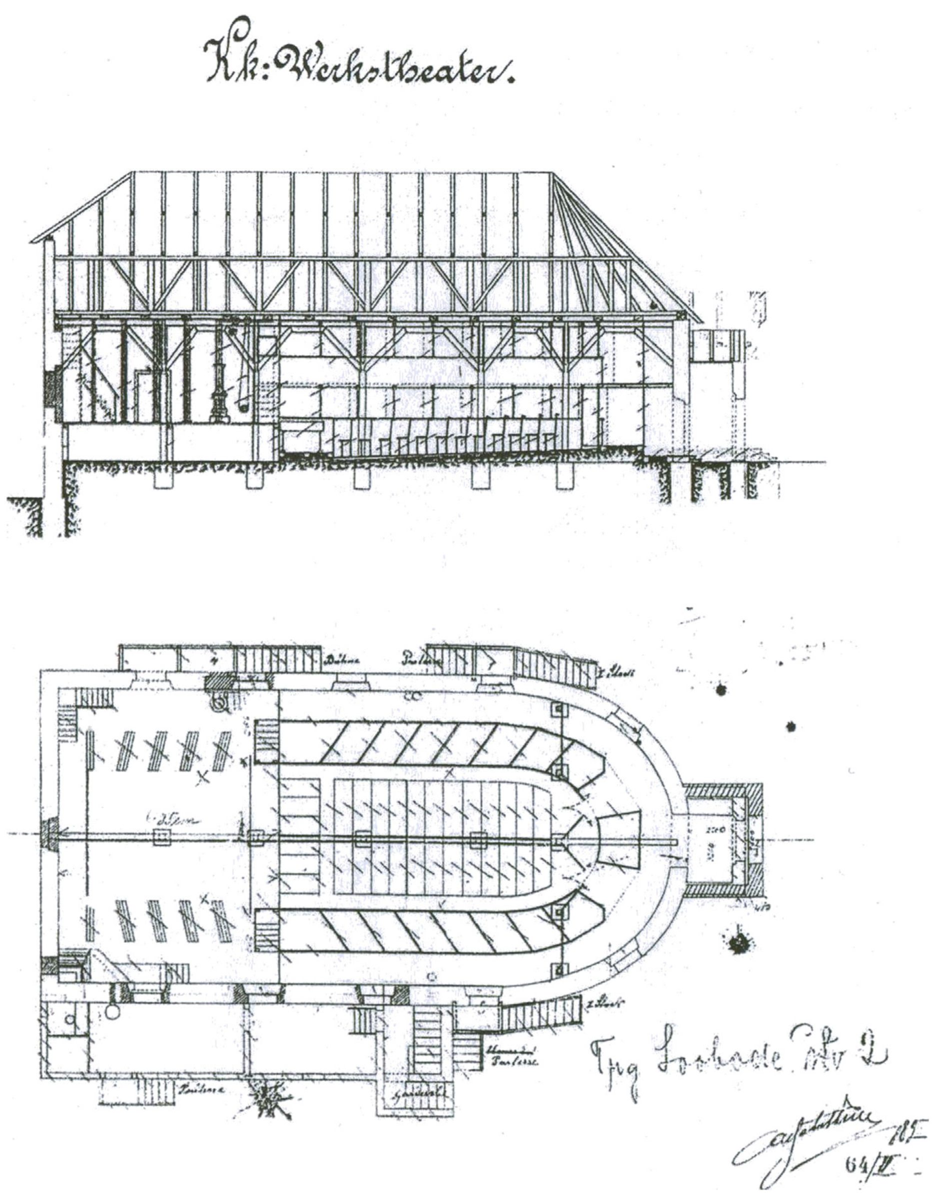

Fig. 1. Cross-section and plan of the Miners' Theatre dated from 1882.

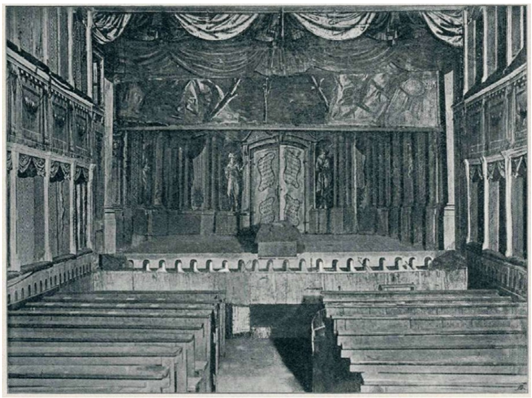

Fig. 2. Picture of the theatre (1905).

Fig. 3. View of the Film Theatre Idrija.

boxes on the ground floor and 19 boxes on the first floor. The boxes were made of wooden material and covered in plaster and with red velvet, and embellished with modest decorative elements. Through two external wooden staircases, it was possible to access the upper boxes. The windows on the ground floor and first floor were at first separate and most likely small and rectangular on both levels.

The only information about the roof is about the building's materials: it was made of wood with a plaster coat.

Until the mid-19th century, German and Italian travelling theatre groups performed in the Idrija theatre and then after 1850, an increasing number of exhibitions were performed in the Slovene language. Thus in 1853 and 1856, they arranged the two famous comedies written by Anton Tomaž Linhart. After 1889, the Idrija Dramatic Society was founded, and in the theatre only Slovene performances were represented.

Restoration of the building structure was performed in different years, in 1823, 1832, 1844, and 1872, although there were no significant interventions on the Baroque design. During the restoration in 1872, the theatre interior was finished by the local painter and sculptor Jurij Tavčar. A more extensive adaptation of the building was completed between 1892 and 1895. Then the exterior was given the appearance it has today. The entrance hall was removed and then replaced with a new one, slightly bigger and higher extension of neoclassical appearance.

Triangular gable, pilasters, garland cornices gave magnificent appearance to the exterior of the new construction. Contemporaneously, other exterior parts were modified; the original small windows were enlarged into tall, semi-circular openings, extending over the height of the two floors, which in the lower part mostly also served as doors for conforming to fire safety regulations.

At the same time, all the external staircases were removed, as well as the dressing rooms on the northern side. In 1895, the Ljubljana earthquake damaged partially the renovated roof whilst the rest of the building started quickly deteriorating and in 1903 the theatre was closed for demolition (Fig. 2).

The boxes and the stage were demolished in 1905 and the building was given over by the mine administration to the municipality to be used to a fire station. In 1913 the building was used again by the Dramatic Society for public works.

The same year, the theatre was partly restored, electricity was installed and a new stage was added. During the First World War, the building was converted into accommodation for prisoners of war and as storage space. Only in 1920, the municipality offered again the permission to stage performances there to the Dramatic Society. At the end of the war in 1918, the Italians occupied Idrija and in 1923 they removed the stage and turned the building into storage space [17–19].

The building continued being utilized as a military centre until after the Second World War. In 1948 the heritage protection service forbids the plan to demolish the abandoned and damaged building. The building was relinquished to the Idrija municipality and in 1952 it was converted into a cinema, based on plans by architect and conservationist Marjan Mušič.

The building continued to be used as a cinema until the floods of 1982. From 1983 to 1987 it was exhaustively refurbished and turned into a film theatre following the design of Silvij Jereb. In December 1988 a fire damaged the interior, and in 1989 it was restored once more with minor modifications. The separating walls in the western semi-circular part of the building were removed during this renovation. Regarding the repair of the exterior, the building was restored giving the appearance of the theatre in the late 19th century (Fig. 3), whilst the interior was converted into a single auditorium with 211 seats. In 2001 it was declared a cultural monument of national importance, together with some other buildings belonging to the former mine [20–22].

3. Acoustic survey

To analyse the acoustic characteristics of the current room (often named "Film Theatre"), an acoustic survey was carried out and several acoustic parameters defined in the ISO 3382-1 [23], were calculated and analysed. Among all the acoustic parameters, in this study, special care was reserved to the values assumed by early decay time (EDT), reverberation time (T_{20} and T_{30}) and clarity (C_{50} and C_{80}), even though other parameters (e.g. Centre Time, STI, LF, IACC) were measured.

3.1. Acoustic measurements

Acoustic measurements were performed to investigate the characteristics of the acoustic field of the current theatre [24,25]. The on-site measurements were carried out using an omnidirectional pre-equalised sound source (Look Line) to generate as excitation signal the Exponential Sine Sweep (ESS) [26,27]. An omnidirectional microphone (Bruel&Kjaer), a dummy head (Neumann KU100), and B-format microphone (Sennheiser Ambeo) were used to get the impulse responses (IRs) from which the main acoustic parameters were calculated. Two positions of the sound source were considered, located on the stage; whilst 13 receiver positions were distributed throughout the area normally covered by listeners. Fig. 4 shows the positions of the sound source on the stage and the thirteen receivers in the stall.

The dodecahedron sound source generated a uniform sound pressure level from 40 Hz to 20 kHz. The output signals, captured by the microphones were stored in a multi-track field recorder, and then post-processed in the laboratory.

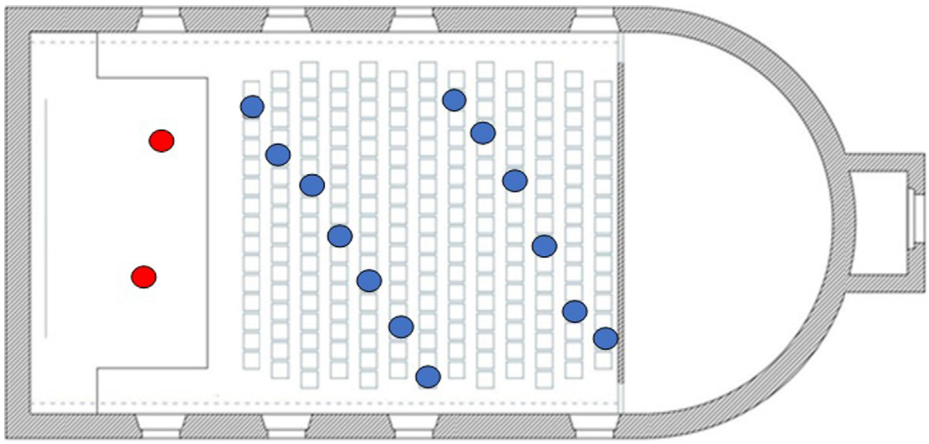

Fig. 4. Actual plan of Idrija's Film Theatre with the indication of receivers (blue points) and sound source positions (red points). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Acoustic measurements were performed in the actual condition of the theatre (Fig. 5), which is completely different from the original building before the renovation.

Fig. 6 reports the measured values of the main acoustic parameters in the octave bands from 250 Hz to 4 kHz. The analysis of reverberation times (T_{20} and T_{30}) showed values always below 1 s, so the Film Theatre resulted in a rather dry room and weak for musical performance but suitable for speech listening. This was confirmed also by early decay time (EDT) which was very similar to T_{20} and T_{30} except in the medium octave bands where slightly shorter values appeared. Furthermore, the values of C_{50} were around 2 dB especially at low and medium frequencies, showed that the room is better suited for speech, whilst the clarity C_{80} was too high and not appropriate for musical performances. Overall, these results are in agreement with the current use of the room, as an auditorium or cinema.

4. Numerical model of the theatre

To investigate acoustics of the original Miners' Theatre before its renovation as cinema-auditorium, a 3D model was created starting from historical research.

A study based on historical pictures and drawings available from the Local Municipality and literature [17,19,22] was performed to understand the original internal volume and shape of the theatre. A geometrical model was created by using the AutoCAD software, importing cross-sections and plans of the theatre (Fig. 1) as raster images, and afterward, they were scaled according to the current dimensions of the Film Theatre (Fig. 7).

The ceiling was modelled accordingly with a cross-section dated from 1989, courtesy provided by the local municipality, and the roof was simulated starting from pictures of the exterior in which it is possible to observe its shape.

A simplified 3D geometrical model was created to perform the simulations (Fig. 8). Very detailed models are known to largely increase computation time without improving results accuracy [28].

Thus, the theatre was acoustically modelled by representing the geometrical characteristics of the original theatre while surfaces were simulated as flat planes to the lack of historical information. This seems not to have much relevance since the modification of absorption and scattering coefficients of richly decorated surfaces that are modelled as flat planes is a common practice [29] because the high level of detail cannot be handled by ray-tracing software. Furthermore, AutoCAD layers were managed considering used construction materials (18 layers in total), and the following materials were selected: lime plaster for the roof, smooth plaster for lateral walls, and velvet for walls of the first and second order.

5. Acoustic simulation

The 3D AutoCAD model was exported in .dxf format and three computer simulations of the acoustic behaviour of the theatre were carried out by using the architectural acoustic software Ramsete [30,31]. This software allows acquiring recommended acous-

Fig. 5. Sound source and microphones during the acoustic measurements.

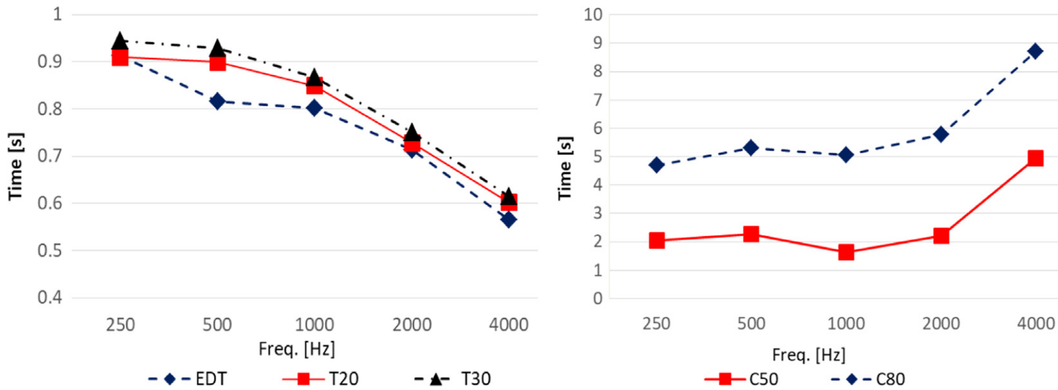

Fig. 6. Results of the main acoustic parameters measured in the Film Theatre.

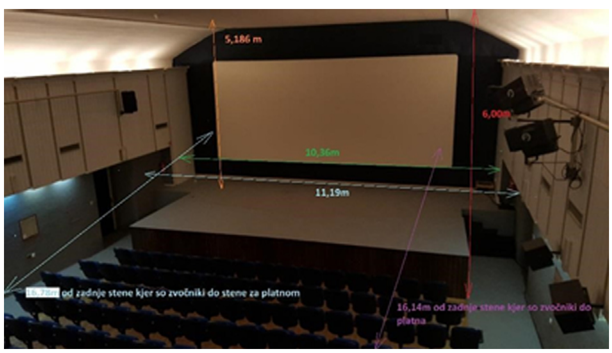

Fig. 7. Actual configuration of the theatre with dimensions.

tics parameters necessary to investigate the acoustic of the simulated building [32,33]. To investigate the acoustic of the theatre in unoccupied conditions without audience and sceneries on the stage (Scenario 1), 93 receivers were homogeneously distributed in the theatre to simulate viewers and an omnidirectional source was located on the stage. The virtual model had the following geometrical characteristics: number of surfaces 1350, total surface area 1709.6 m^2, and volume 1467 m^3. Table 1 reports the absorption and scattering (s) coefficients for all the materials considered in the simulation. The scattering coefficients were obtained from the literature [34,35]

In this study, the calibration of the model was not conducted comparing experimental measurements with simulated data, because the actual building differs considerably from the original one. However, the values of the sound absorption coefficients were chosen from the database accordingly with the data utilised during the virtual reconstruction of the *Teatro Ideale* by Francesco Milizia and considering usual literature values [36–38]. So, the defined materials and their absorption coefficients were reported on a specific file.

Once the model was validated for the unoccupied condition, the absorption coefficient of the pew area was modified to simulate the occupied condition (Fig. 9). The acoustic measurements are very difficult to carry out when there are people in the theatre, so in Scenario 2, the presence of the audience is simulated changing the value of the absorption coefficient of the seat surfaces.

The sound absorption of the audience depends on occupation density, posture, and also clothing [39–41] and its value generally used in room acoustic was chosen accordingly with [42]. The scope of this simulation was to understand whether the presence of the

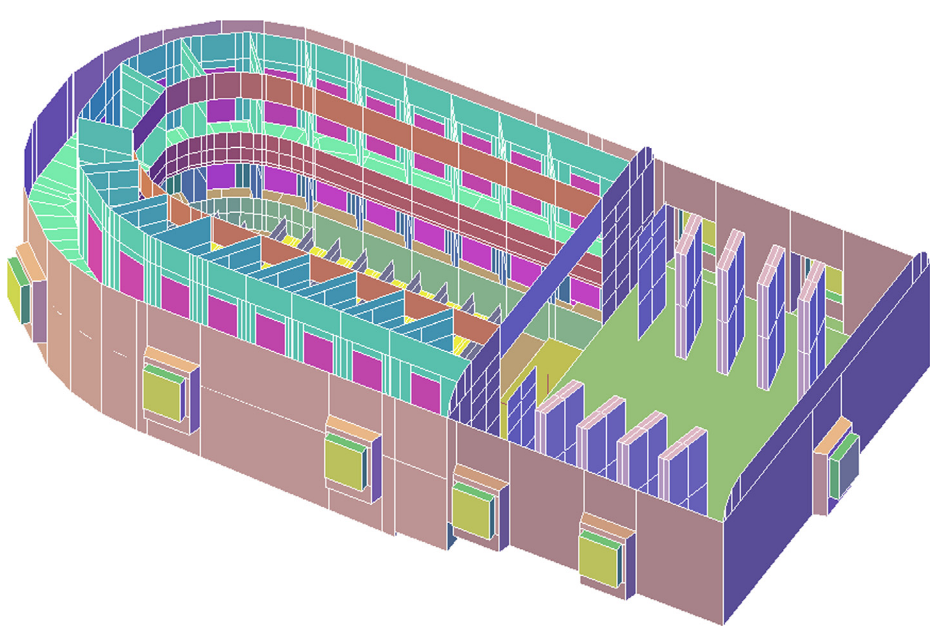

Fig. 8. Realization of the 3D geometrical model of the Miners' Theatre in Idrija.

Table 1
Surface, absorption and scattering coefficients for all the materials considered in the simulation.

Materials	Surface	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	Scattering
Ceiling-plaster	450.0	0.025	0.025	0.025	0.03	0.04	0.05	0.05
Wooden pavement	118.8	0.15	0.4	0.25	0.2	0.3	0.25	0.05
Velvet Curtains	138.3	0.08	0.29	0.44	0.5	0.4	0.35	0.05
Stage Walls	132.2	0.03	0.035	0.035	0.035	0.04	0.045	0.05
Windows-glass	17.6	0.1	0.04	0.03	0.02	0.02	0.02	0.05
Windows-wood	15.3	0.005	0.005	0.009	0.009	0.01	0.01	0.05
Stalls-pavement-Wood	151.6	0.01	0.015	0.025	0.05	0.025	0.06	0.05
Wooden chairs	83.6	0.075	0.09	0.1	0.105	0.075	0.05	0.70
inferior surface-wooden doors	44.6	0.075	0.09	0.1	0.11	0.075	0.05	0.05
superior surface-wooden boiserie	31.6	0.11	0.25	0.35	0.36	0.36	0.365	0.05
superior surface-boxes velvet	175.5	0.181	0.137	0.092	0.074	0.046	0.046	0.50
superior surface-boxes wooden	34.4	0.075	0.09	0.1	0.11	0.075	0.05	0.50
superior surface-pavement	94.0	0.01	0.015	0.025	0.05	0.04	0.07	0.05
superior2 surface-wooden boiserie	26.7	0.11	0.25	0.35	0.36	0.36	0.365	0.05

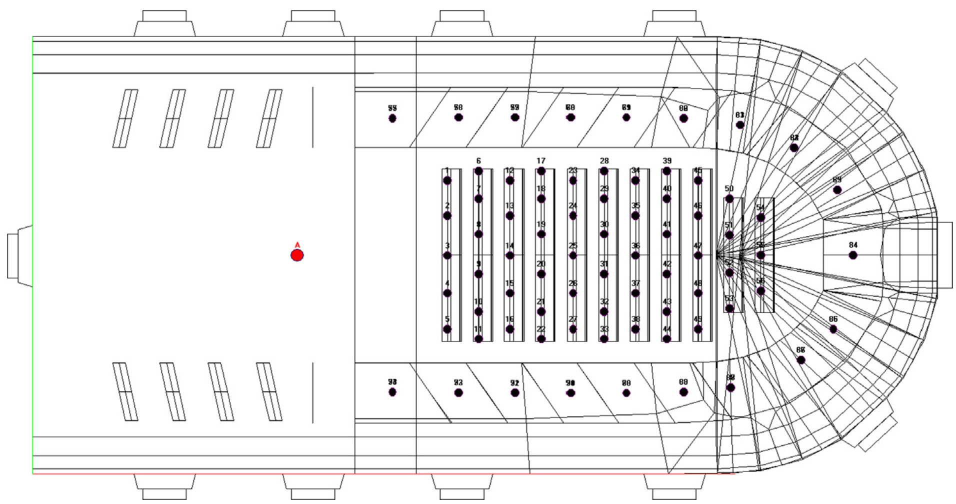

Fig. 9. The virtual model of the theatre in Scenario 1 and 2, with an omnidirectional sound source placed on the stage and 93 receivers in the hall.

audience has a negative role in the overall acoustics of the theatre and if implicates variations of the room's acoustics characteristics.

Finally, taking advantage of the availability of the validated model in the occupied condition, further investigation was carried out (Scenario 3). The effect of sceneries on the acoustic characteristics of theatre has been rarely investigated. Consequently, a new simulation was carried out placing three wood sceneries with different heights on the stage in front of the stalls in full occupancy (Fig. 10), to understand the role of these elements during a performance.

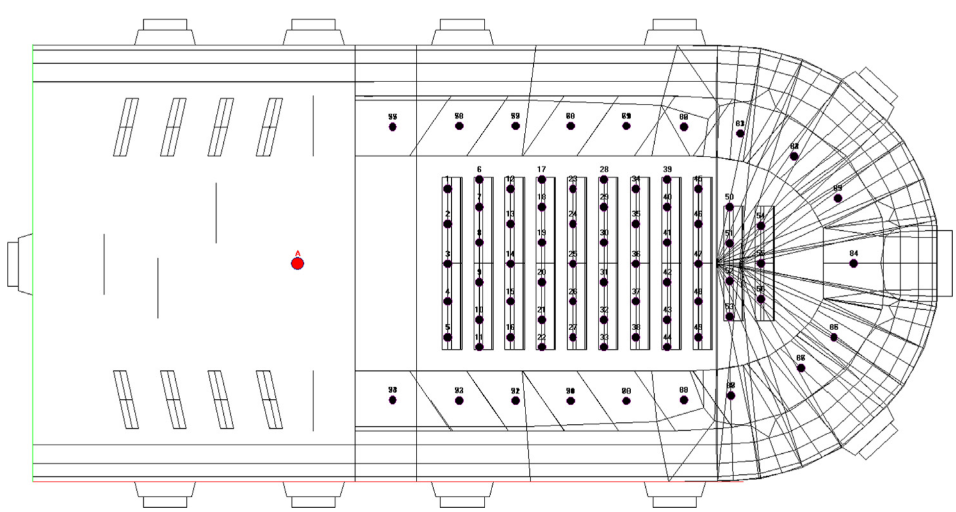

Fig. 10. The virtual model of the theatre for the Scenario 3 with an omnidirectional sound source, three sceneries on the stage, and 93 receivers in the hall.

6. Analysis of the results

Fig. 11 reports the simulated results for acoustic parameters for the three scenarios. Figs. 12–14 the spatial distribution of T_{30}, C_{80} at the frequency of 500 Hz and STI. As can be seen from the graphs, EDT assumes values between 0.73 and 0.77 s for scenarios 2 and 3, while for scenario 1 EDT presents values between 0.82 and 0.92 s. The average value for parameter T_{30} without audience and sceneries is approximately 0.97 s, whereas in full occupancy and with sceneries on the stage the parameter assumes values lower than 0.81 s. A decrease of T_{30} for scenario 3 respect EDT trend can be noticed. Parameter C_{80} assumes values greater than 4 dB in the building for all scenarios, whilst C_{50} assumes values greater than 1.3 dB. The average value of STI = 0.7 corresponds to a good value of speech intelligibility.

Considering the Just Noticeable Differences for these parameters, we could see that EDT and T_{30} are both almost within the JND values in scenarios 2 and 3, while for scenario 1 the variation

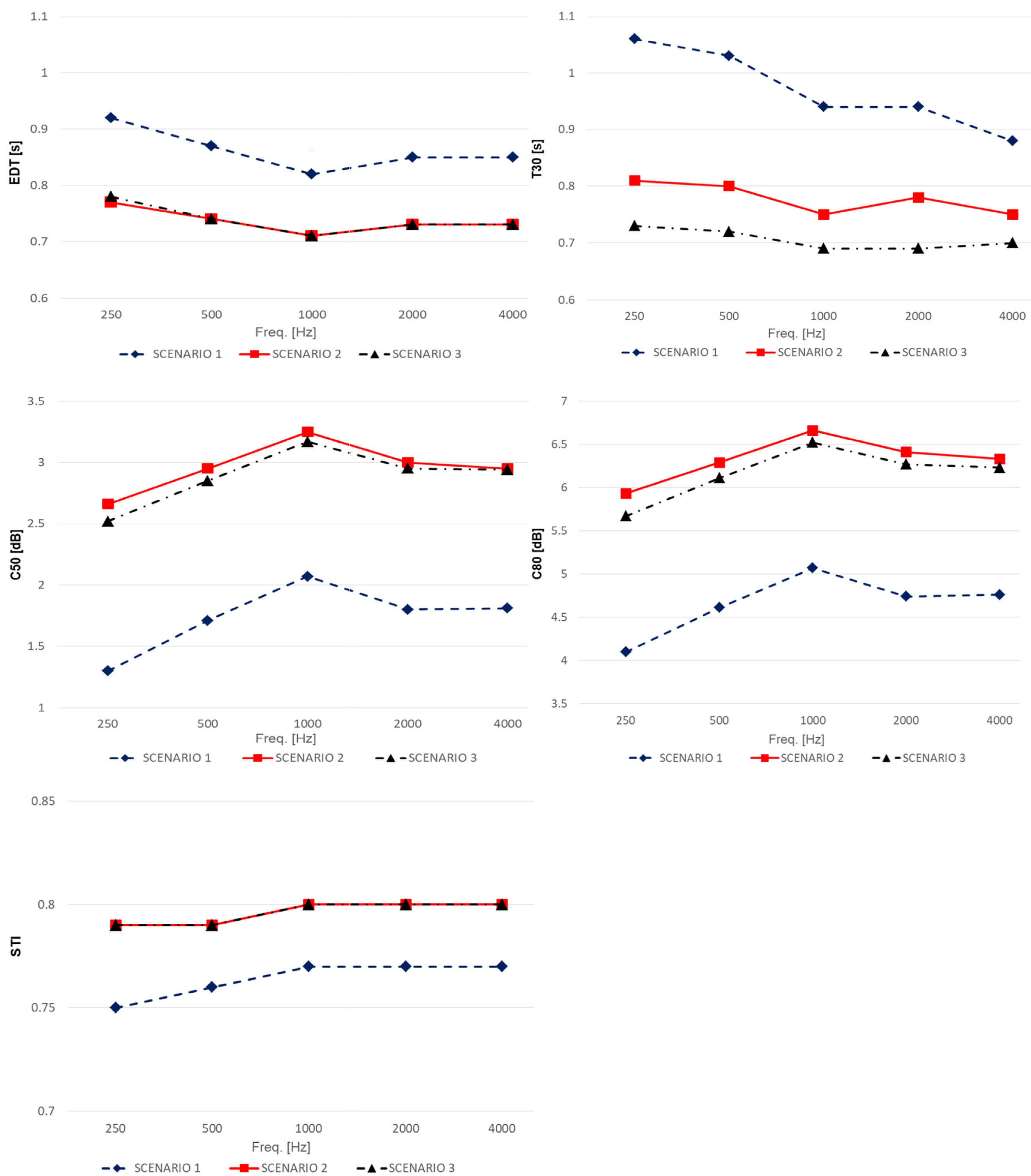

Fig. 11. Average values of the acoustic parameters (EDT, T_{30}, C_{80}, D_{50} and STI) in the frequency domain obtained by simulations.

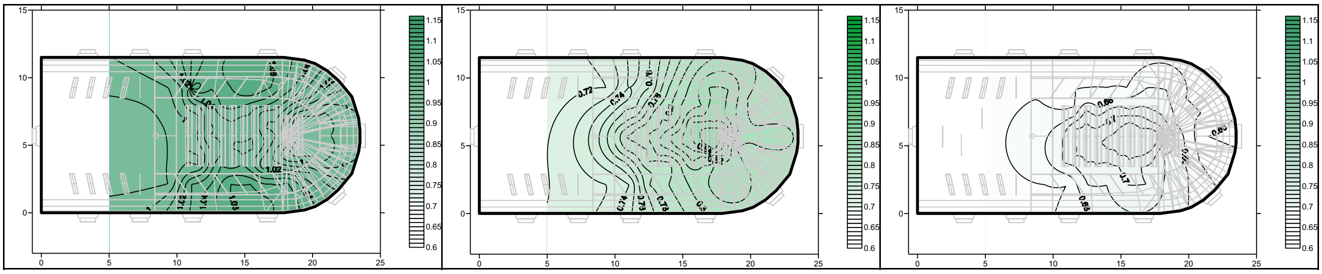

Fig. 12. Spatial distribution of T_{30} at 500 Hz for the three scenarios. (a) Without occupancy; (b) with occupancy; (c) with sceneries and occupancy.

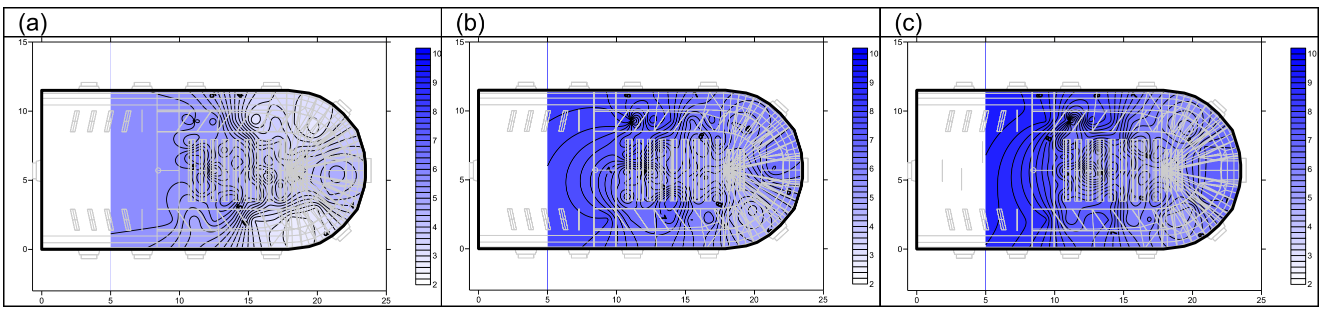

Fig. 13. Spatial distribution of C_{80} at 500 Hz for the three scenarios. (a) Without occupancy; (b) with occupancy; (c) with sceneries and occupancy.

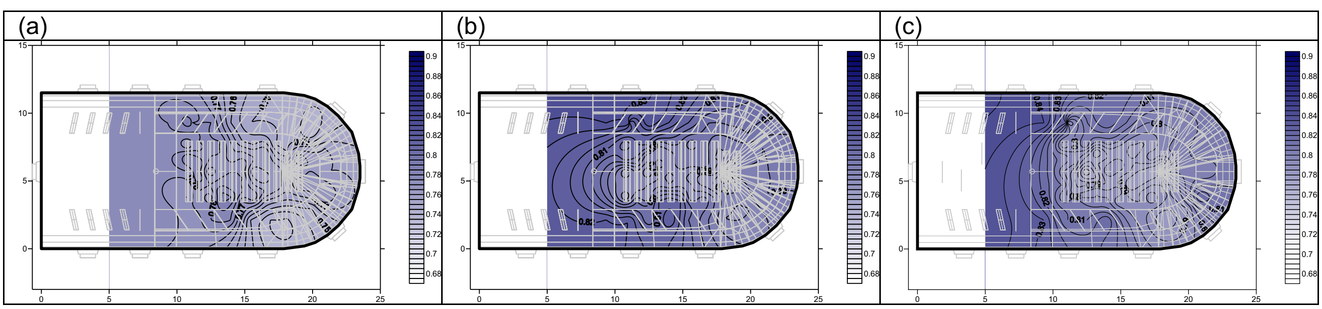

Fig. 14. Spatial distribution of STI for the three scenarios. (a) Without occupancy; (b) with occupancy; (c) with sceneries and occupancy.

exceeds the JND value (i.e. 5%). The same results are found for Clarity (both C_{50} and C_{80}), where the JND value is 1 dB, and for STI, in which the JND value is 0.03.

We also could see a similar result considering the spatial distribution of the same parameters, reported in Figs. 12–14.

7. Discussion

The average reverberation time obtained by simulation without audience and sceneries is low due to the small volume of the hall, but it is in line with the volume-reverberation time trend of theatres (Fig. 15).

From Fig. 11, it is possible to notice that trends of EDT and T_{30} are not linear, but seem to present double slope. This anomalous behaviour is very pronounced when the theatre is empty due to the reflections of the sound waves on the seating rows which, thanks to their reflecting surface, improve the sound amplification at low frequencies. Whilst in scenarios with audience and sceneries, differences between the two slopes are attenuated because of the audience is simulated changing the value of the absorption coefficient of the seat surfaces. Subsequently, the Miners' Theatre has a shorter reverberation time and is acoustically dead. However, this double slope trend is reported even for clarity and the values are too high for musical performance.

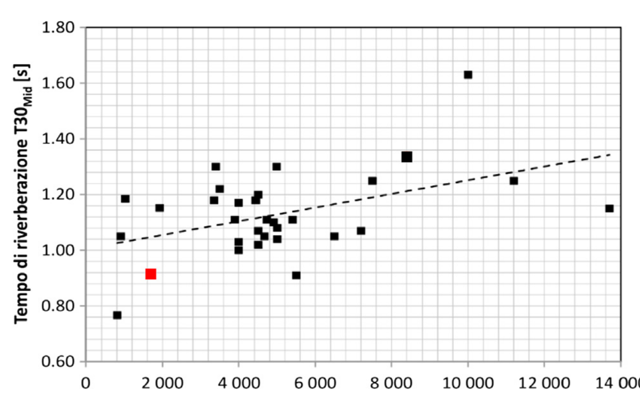

Fig. 15. relation volume – T_{30}; red square is the value of the Miners' Theatre. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Moreover, it is possible to notice a decrease of EDT and T_{30} at the frequency of 1000 Hz. This is a particular aspect of the theatre, in which perceived sound is "brilliant" and it resembles a room with a high percentage of thin glass walls.

The spatial distribution of the acoustic parameters within the theatre is uniform (Figs. 12–14). A considerable difference is found between scenario 1 (without occupancy) and scenarios 2 and 3 (with occupancy), which underlines the remarkable difference of the acoustics in the theatre due to occupancy. The difference, which is greater respect to other opera houses, depends on the small volume of the theatre and the relatively high number of seats, which cause a higher reduction of the reverberant tail when the occupancy is considered.

8. Conclusions

The paper has described the acoustic behaviour of the Miners' Theatre in Idrija in its original conditions without audience and sceneries, in full occupancy and with audience and sceneries on the stage. The results obtained from the elaboration of the virtual model showed that in the original configuration the theatre suited well to spoken performances (with and without audience and sceneries). Moreover, the analysis of the numerical simulations shows that there is the influence of the audience on the acoustics of theatre and the hall results acoustically deaf, whilst the acoustic has not changed significantly with sceneries on the stage.

Therefore, it shows that the theatre had no desirable condition for musical performance.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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