The Acoustics of Kabuki Theaters

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Summary

The study presents a room acoustical investigation of a representative sample of eight Kabuki theaters as the most important public performance venues of pre-modern Japan. Room acoustical parameters according to ISO 3382 were measured for the unoccupied and simulated for the occupied condition. In comparison with European proscenium stage theaters, they have lower room heights in the auditorium, with usually only one upper tier, and no high stage house for movable scenery. The lower volume per seat results in lower reverberation times. The wooden construction and the audience seating arrangement on wooden straw mats on the floor instead of upholstered seats leads to a mostly flat frequency response up to 4 kHz, resulting in an excellent speech intelligibility, as documented by values for definition (D₅₀) and the speech intelligibility index (STI). The acoustical conditions support the dynamic acting space created by pathways extending the stage from the front through the audience to the rear of the auditorium. They allow great contrasts in the perceived acoustical proximity depending on the selected acting position, and support a high degree of immersion of the audience into the dramatic action.

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1. Introduction

The Kabuki is the most important genre of traditional Japanese public theater. During the Edo period (1603–1868), it became the primary form of public entertainment for the growing merchant class in the urban centers of Japan, with a particular type of performance venue. Only after the Meiji Restoration of 1868, characterized by a state driven “modernization through westernization” affecting all aspects of society, theaters inspired by Western models were built in major cities such as Tōkyō and Osaka. At the same time, the industrialization brought city culture to more rural areas and led to an increase in the construction of Kabuki theaters outside the cities. Until today, the Kabuki is a vital form of art, with about 20 active theaters throughout Japan.

The earliest records of Kabuki date back to the beginnings of the Edo period, describing female dance performances accompanied by flutes and drums, which took place on available Shrine stages, as well as on temporary open-air stages in Kyōto. These stages were inspired by existing stages for Nō theater of the time, featuring a roofed stage, while the audience was seated in front of the stage in open air. In 1624 the first permanent theater in Edo (Tōkyō) was established, called Saruwaka-za (later renamed Nakamura-za). It still had no roof above the audience seats, which were placed in front of the stage (hiradoma).

Permanent roofs started to appear from 1670, but it was only after the issuing of fire regulations in 1723, that tiled roofs were required by the government, which needed new supporting structures. This process was an important step towards the development of the physical theater in its final form [1]. In 1724, the three big theaters in Edo, namely the Nakamura-za, the Ichimura-za, and the Morita-za were all completely equipped with plastered walls and tiled roofs. Around the same time, a pathway called hanamichi with about 1.5 m in width, which had started to develop from the end of the 17th century as a temporary extension of the stage, found its final and permanent position at stage right [2, 3]. Starting in 1736, the practice of dividing the pit into rectangular areas of different prices (masu) was introduced. Around 1772 a narrower secondary pathway (kari-hanamachi) was introduced at stage left, and the two were connected by a tertiary path at the back of auditorium (ayumi). Gradually, the theater buildings for Kabuki devel-

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² Source: https://en.wikipedia.org/wiki/Kabuki, accessed: April 17, 2018
opened their characteristics distinguishing them from the Nô stage they had originated from. The roof above the stage, typical of the Nô stage, disappeared from the Kabuki theaters from around 1796. By 1830, the Kabuki theater (or shibai goya as they are usually referred to in Japanese) had reached its mature form [4].

Kabuki performances present a dramatic plot from a standard repertoire of plays created in the 18th and 19th century. Staging historic events centered around the Samurai class or the life of the commoners of the feudal age, these plays consist of a characteristic form of singing, as well as acting and dancing accompanied by music on and off stage. At the core of a Kabuki performance are the so called mie poses, in which the actor stays in a certain pose at the eshichisan point of the hanamichi for a moment to emphasize the action of the plot. These poses, as well as the beginning and the end of a play are accompanied by rhythmical motives, played on woodblocks (ki or tsuke) placed at stage left. A small ensemble of one or more stringed instruments (shamisen), flutes as well as percussion instruments, placed behind a slatted wall on stage right, contribute music and sound effects. Plays can also consist of a narrator sitting on a platform on stage accompanying himself on the shamisen, or passages of acting and dancing without dialog accompanied by a small orchestra of shamisen musicians on stage, which is visible to the audience. The shamisen is plucked with a plectrum and, together with the percussion instruments, forms a rhythmically accentuated background music, while the singers deliver sustained legato notes to it.

In the current study, we present the results of several room acoustical measurement campaigns [5][6], with in-situ measurements and room acoustical simulations of a representative sample of remnant Kabuki theaters. The main goal of the study was to describe the range of room acoustical conditions of this performative genre, with a special focus on the particular features of these venues in contrast to theater buildings in the European tradition.

2. Description of the theaters

All theaters investigated are two-storey wooden structures. They exhibit the typical architectural features of this building type (Figure 2), and all of them are still used for performances of traditional Kabuki plays. Two of them, the Hô-za and the Kanamaru-za, were built in premodern Japan, during the late Edo period (1603–1868), while six of them were built in the subsequent Meiji period (1868–1912). Geographically, the theaters are located in three of the four main islands of Japan, including the islands of Shikoku and Kyūshū in southern Japan, and Honshu as the largest and most populous island in central Japan.

The Kanamaru-za, located on the island of Shikoku and completed in 1835, resembles the Kabuki theaters at the heyday of their development. In terms of size, dimensions, and stage machinery, it matches the dimensions of the three big Edo theaters [7]. The proximity to the Kompîra Shrine, considered one of the most sacred places of worship in Japan, seems to be the reason for finding such a remarkable example of Edo period architecture in the rural area of the Kagawa prefecture. The other theater in the island of Shikoku, called the Uchiko-za, located in Uchiko town, Ehime prefecture, was built in 1916, celebrating the coronation of Emperor Taisho [8].
Figure 2. Drawing illustrating the most important features of a Kabuki theater building: the pathway (hanamichi, A), the seating area in front of the stage (hiradoma) with the seating grid (masu, B), the boxes on the side (sajiki, C), the secondary pathway (kari-hanamichi, D), and the tertiary parallel pathway at the back of the theater (ayumi, E).

Four of the Kabuki theaters investigated are preserved in the Gifu prefecture in central Japan. The Hōō-za in Gero city is the oldest and also the smallest of the theaters studied. The original date of construction as an early shrine stage is unknown (sometime in mid-Edo period) but it was relocated to the current site in 1827 and has been used as a theater since then. The Murakuni-za, opened in 1882 in Kakamigahara city, the Hakuun-za opened in 1890 in Gero city, and the Meiji-za, opened in 1895 in Kashimo village were constructed in the Gifu prefecture in the early years of the Meiji era, when commoners in rural areas of this prefecture came in contact with city culture through the emerging silk industry which resulted in a further development of Kabuki performances and the increased construction of venues for entertainment [9].

The theaters on the island of Kyūshū were also constructed in the Meiji era. They include the Yachiyo-za, opened in 1910 in Yamaga city, Kumamoto Prefecture and the Kaho Gekijo, opened in 1921, located in Iizuka city, Fukuoka prefecture. Table I shows the date of opening, the cubic volume, the capacity and the volume per person for the eight theaters of the current investigation.

### Table I. Year of opening, volume (derived from the geometric models), capacity (derived from the literature), and volume per person for the eight theaters of the current investigation.

| Name        | Opening | Volume (m³) | Capacity (N) | V/N (m³) |
|-------------|---------|-------------|--------------|----------|
| Hōō-za      | 1827    | 790         | 600          | 1.3      |
| Kanamaru-za | 1835    | 2935        | 800          | 3.7      |
| Murakuni-za | 1882    | 1195        | 200          | 6.0      |
| Hakuun-za   | 1890    | 1225        | 400          | 3.1      |
| Meiji-za    | 1895    | 1800        | 500          | 3.6      |
| Yachiyo-za  | 1910    | 1648        | 500          | 3.3      |
| Uchiko-za   | 1916    | 2165        | 650          | 3.3      |
| Kaho Gekijo | 1921    | 3787        | 1200         | 3.2      |

3. Acoustical investigation

3.1. In-situ measurements

In the eight theaters of the current study (Table I), room acoustical measurements according to ISO 3382 were carried out [10], using a laptop-based measurement system and sine sweeps to obtain impulse responses with a length of 1.6 s for different locations of source and receiver. The dodecahedron loudspeaker (TOA AN-SP1212) was placed at a height of 1.5 m, and the microphones were placed at a height of 0.9 m, considering that the audience was sitting on the floor on tatami mats. Measurements were conducted for two source positions on stage and up to 12 receiver positions, depending on the size of the theater (Figure 4).

For two of the theaters (the Meiji-za and the Hakuun-za), an exemplary investigation was conducted, comparing the acoustical conditions for the most important acting positions in the Kabuki play. Besides a stage-front and a rear-stage position, which exist also in theaters of the European tradition, these include a particular location on the Hanamichi pathway, where the most crucial parts of a Kabuki play such as the mie poses are presented. This is a point located seven-tenths away from the rear of the auditorium, or three-tenths away from the stage (shichi-san). Thus, in the measurements and simulations of these two venues, three source positions were investigated:

- **SA** located on the center stage, 0.8 m behind the front of the stage
- **SB** located on the center stage, 5 m behind the front of the stage
- **SC** located on the Hanamichi, at the so called shichi-san point

For each source position, 12 receiver positions were measured. Speech transmission index (STI) measurements were carried out using a broadband speaker with a driver of 12 cm diameter.

Room acoustical parameters according to ISO 3382 [10] were derived from the impulse responses, including

- the early decay time EDT as a predictor for perceived reverberance,
- the sound strength G as a predictor for perceived loudness,
- the definition D₅₀ (early to total sound energy ratio) as predictor for speech clarity, and
- the early lateral energy fraction JₐL as a predictor for perceived source width.

3 DSSF3 software, version 5.2.0.15.
http://www.ymec.com/manual/era/impulse.htm
The parameters derived from the measurements were obtained using a Matlab script based on the ITA toolbox [11]. The parameters derived from the simulations were calculated in the software (see 3.2).

3.2. Simulations

For the acquisition of the geometry of the theaters, three-dimensional point cloud data of the Meiji-za, Hakuun-za, Kanamaru-za and Uchiko-za was obtained using a commercially available laser scanner. For the other theaters the geometry was determined using a laser distance meter. Based on plan and section cut images exported from the laser scans, as well as on architectural drawings and pictures, computer models were created for the eight theaters, using SketchUp Make 2017.

As a general guideline, we have attempted to keep a minimum structural size of 0.5 m in the room acoustical models, which has turned out to deliver the best simulation results [13, p.176], resulting in models with a number of 100 to 300 faces. Scattering coefficients were set as suggested in [14] (a scattering coefficient at 707 Hz is specified and a frequency function of rising scattering values increasing with frequency is extrapolated).

For the stage and the Hanamichi, absorption coefficients for wooden floor on joists were applied [15], while for the unoccupied and occupied Tatami, absorption coefficients were determined by own measurements (Section 3.3).

The remaining surfaces include different, mostly wooden materials, whose absorption values are quite homogeneous but cannot be specified exactly by measurements in situ. Therefore, a “residual” surface was assigned to all remaining surfaces and the values were fitted so that the resulting room average reverberation time would match the measured results within a JND of 5% as described in ISO 3382. In the model, an omnidirectional source and listeners were inserted at locations corresponding to the microphone positions in the in-situ measurements. The simulations of the speech transmission index (STI) were carried out using the source directivity of a male speaker [16], assuming a normal vocal effort as defined in ANSI 3.5 [17] with a background noise level applying the NC 25 curve. The simulations were further veri-
fied by comparing the measured and the simulated STI values, which showed a difference of below 0.05 in all cases. The simulations were conducted using a hybrid mirror image/ray tracing algorithm [18].

3.3. Measurements of absorption coefficients

A main difference between the Western theater and the Kabuki theater of Japan is the seating arrangement. The audience is not seated on chairs but on rice straw mats called tatami. Since absorption coefficients of audience seated on Tatami, especially with respect to historical seating density were not available, measurements of the sound absorption according to ISO 354 [19] for unoccupied Tatami as well as for audience sitting on Tatami were carried out in the reverberation chamber of TU Berlin (V = 200 m³). A test specimen consisting of six Tatami with a total surface area of S = 9.7 m² was placed on the floor of the chamber (type A mounting). The perimeter of the test specimen was sealed with an acoustically reflective frame made of 30 mm thick wood.

For the measurements of the absorption coefficient in the occupied case, two Tatami with a total surface area of 3.2 m² were placed in the corner of the reverberation room. To obtain absorption coefficients of an “infinite surface”, the edges of the test specimen were covered with 500 mm high and 30 mm thick wood panels to avoid the increased aisle absorption, as suggested in [20]. To compensate for the increased sound absorption due to the 3 dB higher sound pressure level in the edges, a correction was applied as suggested by [21], enlarging the test surface by a strip of width b, where b = ām/8.

According to [4], the three Edo theaters in 1841 accommodated five persons in one seating box (Masu), measuring 1.3 m by 1.35 m. In later years, it was tried to increase the capacity of the theaters by reducing the size of one rectangle to 1.2 m by 1.3 m. While the exact size of these rectangles and the number of persons seated there changed over time, seating ten persons on two Tatami (3.2 m²) seems to be a plausible average of the historical seating density in the Kabuki theaters. Therefore, on two Tatami, ten persons (five male, five female) were seated in three rows of two, three, and two persons resulting in a comparatively tight seating density of approximately three persons per m². Another factor influencing the sound absorption is the clothing of the audience. Therefore, measurements were performed with persons wearing jackets and persons wearing no jackets. In Figure 5 the sound absorption coefficients α for Tatami as well as for persons sitting on Tatami with different clothing are shown. The values derived from the measurements were converted to octave band values according to ISO 11654 [22] for the use in the simulations described in Section 3.2.

4. Results

4.1. Reverberation times

The room average reverberation times values for the unoccupied case derived from the measurements and the occupied case derived from the simulations are shown in Figure 6. For the room averages, the central front stage position and all receiver positions were used. The values for the occupied state are slightly different from a previous publication [23] due to the application of the measured absorption coefficients of Tatami now available.

The reverberation times of the unoccupied theaters are in the range of 0.6 to 1.0 s, with the Murakuni-za and the Kaho Gekijo slightly exceeding this range below 500 Hz. The longer reverberation times in the case of the Murakuni-za despite the rather small volume of V = 1195 m³ can be attributed to the fact that this was the only theater within the sample not equipped with a tatami floor as well as to a high ceiling height compared to the floor space. Values for the occupied state are in the range of 0.4 to 0.8 s, with only the Kaho Gekijo, the largest of the theaters measured, exceeding this range with Tm = 1.0 s.

The bass ratio (BR) assumes values between 0.9 and 1.3 in the unoccupied condition, rising to between 1.0 and
Figure 6. Reverberation times for the eight Kabuki theaters investigated. Values for the unoccupied case are derived from measurements (a), for the occupied case from simulations (b).

1.5 in the occupied condition. Towards higher frequencies, the reverberation times of all Kabuki theaters except the Murakuni-za are characterized by an almost flat frequency response up to 4 kHz.

4.2. Early reflections

Individual early reflections, which can make a noticeable contribution to the acoustic characteristics of a room, arrive at the listener for times below the perceptual mixing time, which is between 50 and 100 ms for rooms of this size[24].

For this time window, Figure 7 shows the typical pattern of early reflections appearing for different positions of the actor on stage, both from measurements in the Hakuun-za theater. With the source located at the center stage position (top), the direct sound is followed by stronger frontal first-order reflections from the floor (1), an upper reflection from the gable roof (3), a lateral reflection from the slanted walls on the side of the stage (4), and a lateral reflection from the sidewalls (5). Another strong reflection arriving approximately 7 ms after the direct sound (2) seems to be a lateral second-order reflection from the side of the Hanamichi and the floor.

With the source located at the Hanamichi, strong frontal first order reflections can be identified coming from the floor (1), upper reflections from the two sides of the gable roof (2,3), as well as a late frontal reflection from the back wall of the stage (4).

4.3. Room acoustic parameters

The room average values of the reverberation time T\textsubscript{20}, the early decay time EDT, the sound strength G, the definition D\textsubscript{50} and the speech intelligibility index STI for the unoccupied and the occupied case are shown in Table II.

Values for D\textsubscript{50} between 0.68 and 0.91 and for the STI between 0.63 and 0.74 (both occupied) illustrate the excellent speech intelligibility in all theaters. This is additionally supported by room average values for G between 6.0 and 9.7 dB.

The values for sound strength G at individual listening positions in the eight theaters (occupied) are between 3.4 and 12.9 dB. The decrease with increasing source-receiver distance is shown exemplarily for the Kaho Gekijo theater (Figure 8), with simulated values for the occupied condition compared to predictions by the classical diffuse field theory and Barron’s revised theory [29, 30]. Although the revised theory systematically overestimates the simulated
values by about 1 dB, it offers a consistently better fit than the classical theory, also in all other theaters considered.

The values for early lateral energy fraction $J_{LF}$, calculated for the Meiji-za and the Hakuun-za theater (Table III) are similar to those reported for 19th century theaters in Vienna such as the old Burgtheater ($J_{LF} = 0.15$), the Kärntnertortheater ($J_{LF} = 0.25$) and the Theater an der Wien ($J_{LF} = 0.25$) [27].

### 4.4. Room acoustics and acting position

In contrast to the classical European proscenium stage the Kabuki theatre allows actors to take up different positions in front of, inside and behind the audience. By the example of two theatres (Meiji-za and Hakuun-za), Table III and Figure 9 illustrate the acoustic effect of the different acting positions (main stage front, main stage back, Hanamichi pathway). With Speech Transmission Indices $STI \geq 0.65$ and $D_{50,m}$ values $\geq 0.73$, speech intelligibility is always good regardless of the source location in both theaters. Nevertheless, there is a notable increase of both loudness ($G_m$), intelligibility ($STI$) and direct-to-diffuse ratio (as characterized by $D_{50}$) with the speaker moving from stage back to stage front to the Hanamichi position. The big difference between the stage back and stage front positions is due to the absence of a stage canopy, which is why the rear position is only supported by a weak ceiling reflection at the lower edge of the stage portal. As the most important acoustical cues for the perceived distance, these differences between the acting positions entail notable different sensations of proximity between actors and audience.

As an example, the spatial distribution of STI values for the three source locations (Figure 9) illustrates how different parts of the audience are addressed by different positions of the actors and how the sensation of being *within* the dramatic action evolves, when taking into consideration that the actors can freely move between these points, and that several actors can be positioned at different locations at the same time.

### 4.5. Original Data

The original CAD-Models (.skp) of the eight theaters, including the source and receiver positions used in the mea-
measurements and simulations are available as an electronic publication [28].

5. Discussion

The Kabuki as the most important traditional Japanese public theater form with its characteristic mixture of spoken and sung vocal passages with instrumental accompaniment has brought forth also a particular architectural type of performance venue. It is a usually two-storey building with a rectangular floor plan, and with the audience sitting on Tatami mats on the floor and on one surrounding gallery. Measurements and simulations of a representative sample of eight Kabuki theaters built between 1827 and 1921 (late Edo, Meiji and Taisho period) indicate the characteristic acoustical conditions of this genre. In comparison with European proscenium stage theaters such as the Viennese court theatres or the small Italian opera houses of the same epoch (Figure 10, [25, 27]), the Kabuki theaters are less reverberant relative to their size due to the relatively small volume per seat of 1–4 m³, except of one venue which is slightly larger. Although Kabuki plays combine elements of song, pantomime and dance with instrumental accompaniment, the acoustical conditions consistently seem to be designed for optimal speech intelligibility, which is indicated by early to late energy ratios (D_{50,m}) above 0.68 and speech transmission indices (STI) above 0.63 in the occupied condition, as well as a rather flat frequency-dependent reverberation time for all theaters of the sample up to 4 kHz. The conditions in terms of size and reverberation are most comparable with those of English theaters from this period such as Theatre Royal in Bristol or Wyndham’s Theatre in London [26].

One main difference when comparing the Kabuki theater to most stages in European tradition is "the unlimited freedom of its theatrical space where stage and auditorium merge and actor and audience sympathetically fuse into one" [7, p. 49]. This is achieved by an extension of the main stage by three pathways surrounding the audience, with the Hanamichi (stage-right) as the most important. Together with the seating arrangement, which does, unlike European proscenium theaters, not predetermine the spectators’ viewing direction, this creates a dynamic performance space and a high degree of immersion into the dramatic action with respect to the social, visual and acoustical experience, as illustrated both by the overall change in room acoustical conditions and the spatial distribution of room acoustical parameters such as the speech transmission index (STI) for the different acting positions.

These acoustical conditions characterize not only the experience of the audience of a theatrical genre of particular importance for Japanese culture, with its peculiar mixture of spoken theatre and music; they also they characterize the cultural experience of a Japanese audience with the room acoustic conditions of music and theater performances in general, at a time when Western concert culture came to Japan after the opening of the country following the Meiji Restoration of 1868. In contrast to a Eu-
European audience whose experience was shaped by a variety of performance venues including large and reverberant spaces such as churches, large baroque festival halls, or even by Renaissance music theater in rooms with 2–3 s reverberation [32], the Japanese audience only knew open-air performances, such as the older Nō Theater, and the conditions of the Kabuki theater represented by the sample of rooms described here, with a densely packed audience and very clear acoustics. Western room acoustic standards for musical concerts with a reverberation time of about 2 s were thus highly unusual for a Japanese audience and could establish themselves only with a great delay in the second half of the 20th century [33].

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