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A portable noise-absorbing recording chamber for sound recordings of archaeological idiophones

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(with 9 figures)

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Abstract

The article initially deals with the difficulties that can arise when sound recordings of archaeological sound objects are made in museum rooms. In order to reduce these problems as much as possible, a simple but effective, sound-reduced recording chamber has been developed. It is used in the FWF (Austrian Sciences Funds) project "Metallic Idiophones between 800 BC and 800 AD", which investigates bells, pellet bells, and jewelleries with jingles. The chamber was constructed from 8 mm thick poplar plywood panels. Its isolation consists of a double layer of mineral wool, Rockfon Facett Plano 20 mm. Measurements have shown a reduction of background noise by up to 21.4 dB SPL in various museum rooms. The transportable recording chamber is weighing only 7 kg and is therefore ideally suited for sound recordings in museums and other collections. This article describes shortly the making of the chamber and examines its noise reduction levels by means of a series of measurements.

Keywords: music archaeology, acoustics, sound recordings, noise-absorbing recording chamber.

Zusammenfassung

Der Artikel geht zunächst auf die Schwierigkeiten ein, die bei Tonaufnahmen archäologischer Klangobjekte in Museumsräumen entstehen können. Um diese möglichst zu reduzieren, wurde eine einfache aber effektive, schallreduzierte Aufnahmekammer entwickelt, die im Rahmen des FWF (Fonds zur Förderung der wissenschaftlichen Forschung)-Projektes „Metallic Idiophones between 800 BC and 800 AD“, bei dem Glocken, Schellen, und klingender Trachtschmuck untersucht werden, eingesetzt wird. Der Kasten wurde aus 8 mm dicken Pappelsperrholzplatten zusammengesetzt und mit einer Dämmung Steinwollplatten, Rockfon Facett Plano 20 mm, innen

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beschichtet. Messungen haben eine Reduzierung der Hintergrundgeräusche um bis zu 21,4 dB SPL in den verschiedenen Museumsräumen, aufgezeigt. Der 7 kg schwere transportable Aufnahmeraum eignet sich daher ideal für Tonaufnahmen in Museen und anderen Sammlungen. Der Artikel beschreibt kurz den Bau der schallreduzierten Aufnahmekammer und prüft ihre schallreduzierende Wirkung durch etliche Messungen.

Schlüsselwörter: Musikarchäologie, Akustik, Tonaufnahmen, schalldämpfende Aufnahmekammer.

Introduction: definition music archaeology

Music archaeology is a special field within archaeology and musicology. Music archaeology is not to be equated with the archaeology of music, but includes the evaluation of sound tools discovered in the ground, iconographic representations and written antique sources such as compositions and reports on the practice of music in past epochs and cultures (Hickmann 1997). Music archaeology uses archaeological methods such as the description of the shape, material, finding positions, dating and use of the sound object as well as musicological methods such as instrumental classification, playing techniques and acoustic analyses to determine pitches and sound levels. A further field of activity is the reconstruction in experimental archaeology (Pomberger 2016). Room acoustics, another field of research in music archaeology, investigates acoustic conditions in former and reconstructed sound spaces (Dauvois 2005: pp. 215–241; Reznikof 2012: pp. 45–56; Pomberger *et al.* 2014: pp. 97–114; Pomberger & Mühlhans 2015: pp. 18–28; Till 2019: pp. 661–692).

The term "soundscape" created by the US-American composer Ralph Murray Schafer refers to the acoustic environment of a landscape or settlement (Schafer 1977, 1994). His ideas and studies subsequently inspired many music archaeologists. Studies on the acoustic evaluation of prehistoric settlement areas and landscapes were produced (Lund 2008: pp. 12–29; Diaz-Andreu & Mattioli 2016: pp. 1049–1058; Rainio 2012: pp. 373–385). Ricardo Eichmann introduced the German expression "Klanggestalt" (sound shapes) in the sense of "specific sound" of musical instruments into music archaeology: *„... Der Erfolg derartiger Rekonstruktionen hängt sehr von der Methode des Nachbaus ab, der sich soweit wie möglich an den historischen Vorbildern orientieren sollte. Ein Aspekt des historischen Nachbaus betrifft die antiken Gestaltungsprinzipien und die Dimensionierung des Instruments im Layout. ...“ ("... The success of such reconstructions depends very much on the method of reconstruction, which should be based as far as possible on the historical models. One aspect of historical reconstruction concerns the antique design principles and the dimensioning of the instrument in the layout. ...")* (Eichmann 2004: pp. 363–371). The Austrian research project "Metallic Idiophones between 800 BC and 800 AD", funded by the Austrian Science Fund, is also breaking new ground. For the first time, the sounds of metallic idiophones will be examined for their psychoacoustic parameters and their psychological effect on human health, thus setting new standards in music archaeology.

The project "Metallic Idiophones between 800 BC and 800 AD in Central Europe"

The FWF (Austrian Science Fund) Hertha-Firnberg-research-project "Metallic Idiophones between 800 BC and 800 AD in Central Europe", which is carried out at the Natural History Museum Vienna, Austria, uses a music-archaeological approach to study metal objects with rattling plates and rattling rings, ringing costume jewellery, and bells and chimes from the Iron Age, the Roman Empire, and the Early Middle Ages. The shape of the objects and their position in the archaeological context allow conclusions to be drawn about their use. Extensive metal analyses will be carried out within the framework of the project in order to obtain information on the metallurgical composition of the objects' alloys, which in turn will also influence their tonal appearance. Reproductions by means of experimental archaeology are planned in order to be able to reconstruct their production. Sound recordings of each individual object – as long as it can be played without being damaged – will be made in a portable sound-reducing recording chamber. The recordings will be analysed by means of an audio-visualisation programme for basic spectral and temporal characteristics such as fundamental frequency, partials, and decay time (BISMARCK 1974: p. 149), but more complex sound characteristics will also be extracted. The analysis consists of a variety of features on low-, mid- and high-level features. The sounds of objects generate acoustic fields, influence the acoustic environment of people and thus their listening habits. For the first time in the history of research in music archaeology, sound objects are examined for their psychoacoustic parameters. Another essential part of the project is the investigation of the influences of sounds on the human psyche and health, which will be carried out using methods of experimental stress research (LINNEMANN *et al*. 2017a, 2017b). Several of the objects under investigation were discovered in graves directly next to the skeleton. Traces of textiles still adhere to some of them and thus provide clues to their function as a sounding component of human clothing. In addition, ancient written sources are consulted to gain further insight into the use of the sound objects. Clothing in prehistory and early history in its significance as a visual means of communication (see EDMONTSON 2008) has already been the subject of various research projects of the Natural History Museum Vienna (see GRÖMER 2016: pp. 428–445).

The problem of acoustic sound recordings in museums

The Viennese Otto Seewald laid the foundation for this discipline with his dissertation "Knowledge of Stone Age musical instruments" in 1933, published in 1934 (SEEWALD 1934). He collected all the information available to him on prehistoric musical instruments in Europe originating from archaeological contexts, described, drew, interpreted, and assigned them to the corresponding epochs and cultures. Furthermore, he classified the instruments instrumentally according to the systematics of the musical instruments of Eduard von Hornbostel and Curt Sachs (HORNBOSTEL & SACHS 1914: pp. 553–590).

He is also the first music archaeologist who was interested in the pitch analysis of prehistoric musical instruments. He examined the Bronze Age vascular flute of Vörösmart (Zmajevaz) in Croatia (Seewald 1959: pp. 111–121.) and the Late Neolithic vascular flute of Perchtoldsdorf in Austria (Seewald 1965: pp. 176–182). He writes: *"... Die tonometrische Untersuchung des Instrumentes erfolgte am Elektrotechnischen Institut der Technischen Hochschule in Wien mit Hilfe eines Frequenzgenerators ..." ("... The tonometric analysis of the instrument was carried out at the Electrotechnical Institute of the Technical University in Vienna with the aid of a frequency generator ...")*. Seewald had the opportunity to examine the musical instruments in a low-noise room.

However, not always a music archaeologist is in the lucky position to bring the sound artefacts into a recording studio and make excellent sound recordings. Rather, one examines the sound objects in previously unknown rooms of various museums and thus experiences their nasty surprises. Disturbing noises can come from anywhere. Unpleasant sound sources are, for example, conversations, phone calls, and burps of other people, who stay in the same room, the ringing of telephones and mobile phones, the whirring of lamps and appliances, machine noise from a neighbouring room, the clattering of computer keys, gurgling of water pipes, street noise coming in through a closed window, movements and kicks of footsteps, and footsteps sounding through walls and ceilings. There are also sounds from air conditioning and many other disturbing sound sources. However, background noise cannot be easily avoided and has negative effects on the sound recordings.

Sound continues in gaseous, liquid, and solid matter: *"... sound is the mechanical vibration or wave movement of the particles of an elastic medium ..."*. The building industry differentiates between airborne sound: sound propagating in the air, structure-borne sound, sound propagating in solid materials, and impact sound: sound produced as structure-borne sound when walking on a ceiling and similar direct excitation of a ceiling, which is partially radiated as airborne sound. One knows longitudinal waves (extension and density waves) as well as transverse waves (bending waves) (Schmidt 1981: p. 90). In the building industry, attempts are being made to reduce the sound waves in buildings through airborne sound insulation, structure-borne sound insulation, and impact sound insulation. Noise insulation in buildings should include sound absorption (noise reduction within a room, audibility within event rooms), sound insulation (noise reduction in shafts and ducts, for ventilation systems and exhaust, and exhaust pipes), and vibration insulation (vibration and structure-borne sound insulation for buildings, machines, installations, and vehicles) and should be taken into account in the planning stage (Schmidt 1981: pp. 88–128). The basic measures for minimum sound insulation are laid down in the standards DIN 4109 2018 (https://www.baunetzwissen.de/bauphysik/fachwissen/schallschutz/mindestschallschutz-nach-din-4109-1-2018-6444996; Accessed 2020-06-23). Loudness is the measure for the perceived sound sensation and is measured in phon. The table of characteristic sound levels shows loud street noise and radio music at 80 phon, restaurants and entertainment at 70 phon, quiet living rooms and clock ticks at 30 phon.

As previous experiences with sound recordings of metal and ceramic idiophones have shown, difficulties arise even in rooms that are perceived as "quiet", because the sounds and sound levels of sound tools are extremely quiet (Pomberger 2016). Therefore, the authors were faced with the question of how it would be possible to produce the quietest possible, interference-free sound recordings for all the artefacts included in the project, which are to be recorded, under the same acoustic room conditions. The idea was born to build a portable, compact, lightweight, sound-reduced recording chamber.

Requirements for the sound-reduced recording chamber, material and construction

The chamber should initially be stable and lightweight and easy to transport. A large part of the trips to the museums planned for the project "Metallic Idiophones between 800 BC and 800 AD" will be made by train. The chamber should be well insulated against disturbing environmental noise. The interior of the chamber should be large enough so that the largest instrument to be examined and the hands that shake or strike it to make it sound also fit into the room. A measuring microphone and a webcam should also be mounted in the interior at specific positions. The webcam should be used to record and check what is happening in the chamber. A detachable, easily closable lid allows the sound objects to be placed inside. A hole, the diameter of which should be dimensioned so that one arm fits through, should be drilled at the front of the chamber. For bells whose clapper is corroded – and this is the case with almost all bells – a round hook should be screwed to the inside of the cover so that the bell can be hung on it to be struck with an external clapper.

In addition to the cylinder closed on both sides, the closed cube is the perfect shape for a receiving chamber. Six plates joined together at right angles form a stable construction. The individual plates behave towards pressure loads like a frame stiffened by a diagonal (Gábor 1968: pp. 30, 33, 61). Starting with the largest object of investigation, a bronze brooch with chains and rattle plates from the Hallstatt cemetery (Kromer 1959), the interior of the chamber had a height of 30 cm plus 10 cm of clearance, and a width and depth of 30 cm.

We decided to use plywood panels made of poplar wood as building material to keep the weight of the construction low (Fig. 1). Poplar is one of the lightest woods with a specific weight of approx. 410 kg/m³ in dry condition. Its tensile strength is 69 N/mm², bending strength 76 N/mm² and compressive strength 36 N/mm². (https://www.holzland.de/holz-lexikon-pappel/ Accessed 2020-06-23). Plywood consists of several – but at least three – layers of wooden panels, which are glued together at an angle of 90 degrees and pressed. Due to the crosswise overlapping of the boards, their swelling and shrinkage is limited. Unwanted movements are thus blocked (https://baubeaver.de/sperrholz-sperrholzplatten/ Accessed 2020-06-23). The technical properties of a 12 mm thick poplar plywood panel are tested with a bending strength of 35 N/mm² according to DIN EN 310

Fig. 1. Construction phase, photo: Beate Maria Pomberger.

(German Institute for Standardization/European Committee for Standardization) (https://www.v-group.com/fileadmin/user_upload/PDFs/Unterlagen_zu_Holzwerkstoffplatten_deu.pdf, Accessed 2020-06-23). We used 8-mm-thick plates, which satisfy our requirements.

Fig. 2. Attaching the insulation boards, photo: Beate Maria Pomberger.

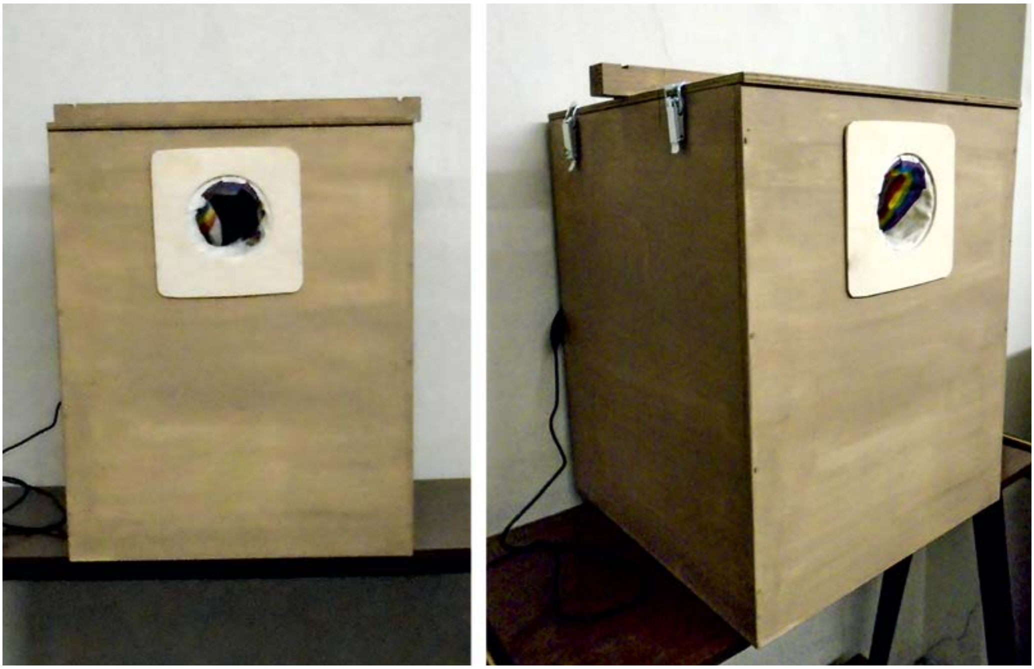

Fig. 3. The finished chamber with cover, photo: Beate Maria Pomberger.

In order to protect the chamber well against disturbing noises from the outside, we chose the insulation product Rockfon Facett Plano 20 mm panels (mineral wool; Fig. 2), which was applied in two layers inside the chamber. Our finished sound-reduced recording chamber (Fig. 3) weighs 7 kg and measures 50 cm × 40 cm × 40 cm. A modified, lightweight, two-wheeled shopping trolley allows the chamber to be transported (Fig. 4).

Fig. 4. The chamber on the transport trolley, photo: Beate Maria Pomberger.

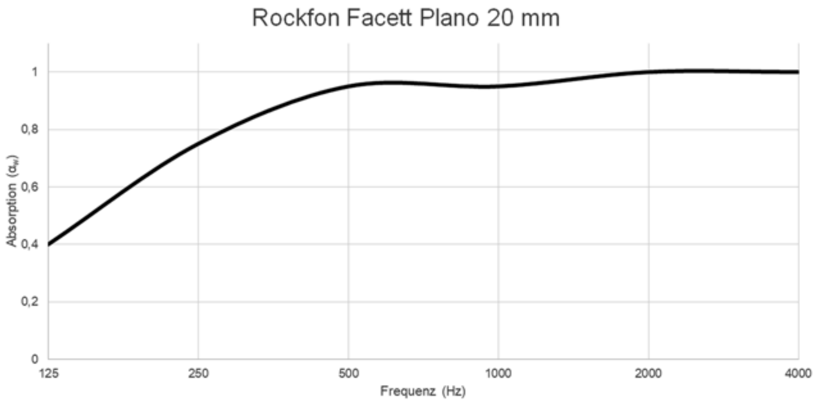

Fig. 5. Sound absorption of the simple 20 mm Rockfon Facett Plano 20 mm (according to Rockfon 2018).

Figure 5 shows the sound absorption coefficient of single 20 mm panels according to the manufacturer's specifications (Rockfon 2018)[3].

The technical equipment inside the chamber consists of a measuring microphone including mounting and a camera to capture the events inside the chamber. On the inside of the back wall of the box the web camera and the mount for the measuring microphone were attached (Fig. 6). Furthermore, an USB interface, a calibrator for the the microphone and a laptop with recording software are required. The calibrator measures the sound pressure level of the incoming signal. For recording and editing Adobe Audition 3.0 was used.

Measurements of the noise level in rooms and testing of quality of the sound reduced chamber

In order to evaluate the expected noise levels, measurements were carried out in different rooms of the Natural History Museum Vienna. For this purpose, different types of rooms were selected which could presumably be made available for measurements in different museums, such as work rooms, meeting rooms, libraries, workshops, storage rooms, and others. It can be assumed that the recording environments in the individual museums are quite comparable from an acoustic point of view, since the noise that could negatively influence recordings comes from very similar (sound) sources.

Background level (or noise level) refers to the totality of sound events in a room that would disturb a sound recording in that room. These can be very loud individual

[3] https://www.rockfon.de/siteassets/commerce/de/tiles/documents/produktdatenblatter/de-tile-data-sheet-rockfon-facett-plano_d_01_2018.pdf (Accessed 2020-04-04).

Fig. 6. Interior view of the sound-reduced chamber, photo: Beate Maria Pomberger.

sources, such as machines, tools, generators, ventilation, and also people who perform noisy activities such as grinding or sawing. Broadband noise, which is spread over large parts of the frequency spectrum, is particularly disturbing to recordings. Also critical for recordings are interfering noises that contain frequencies in the range of the fundamentals and overtones of musical instruments, which could then be falsely assigned to the instruments. These are, for example, ventilation systems, compressors, or tools. If workshops are near the recording rooms, the noise can also spread to adjacent rooms and even to other floors.

Background levels are measured and averaged over long periods of time in order not to overestimate individual loud noises, but to map the entire background noise. For this purpose, the equivalent A- and C-weighted continuous sound levels (LAeq, LCeq) are measured. The frequency weighting filter A represents the human auditory system and weights frequencies in which the auditory system is insensitive to noise to a lesser extent, the frequency weighting C is approximately linear. In addition, level peaks were also measured (LApk, LCpk) in order to be able to evaluate individual loud noises separately. The measurements were performed with the NTi X2 sound level meter and the class 1 measurement microphone M2215. A low LAeq of 40.6 dB was measured only in one room, the "Eiszeit" depot, a value, which according to literature corresponds roughly to the level of a living room in a quiet area or that of a library[4] (Howard & Angus 2009: p. 92; Möser 2009: p. 6). This level was the lowest measured and can at most be described as "acceptable" for instrumental recordings. Ideally, the background level should not exceed the equivalent input noise[5] of the microphone used. For this project, a Presonus PRM 1 measurement microphone with an equivalent input noise of 26 dBA is used. Basically, the lowest possible level is always desirable for recording rooms.

The sound levels of other measured rooms are significantly higher. In the conference room, a LAeq of 50.1 dB was measured, in the management 51.4 dB, in the library even 58.4 dB, and in the workshop 60.0 dB. Libraries in particular are assumed to be very quiet rooms, which in reality is rarely the case[6]. If we look at the peak levels of loud individual sound events, we can see about 48 dB LApk in the quietest rooms and up to 80 dB LApk in the loudest rooms – for better understanding that's roughly the sound level present on busy roads (Howard & Angus 2009: p. 92).

These measurements show that even in the private rooms of large museums it is almost impossible to find a quiet environment for high quality instrumental recordings, as the

Fig. 7. Measurements of the effectiveness of the sound-reduced chamber, photo: Beate Maria Pomberger.

[4] The value for a library, which can be seen in the literature, is to be regarded as an ideal case and in reality, is usually considerably exceeded, which is also shown by the measurement in the NHMW library.

[5] The equivalent input noise (EIN) is the noise level produced by the microphone itself that cannot be avoided.

[6] A comparative measurement in the large reading room of the Vienna University Library showed an equivalent continuous sound level of similar value.

Fig. 8. Measurements of the effectiveness of the sound-reduced chamber, photo: Beate Maria Pomberger.

levels are far too high even in the supposedly quiet rooms. An increase of the level by 6 dB means a doubling of the sound pressure – when looking at the figures there is a danger of underestimation. The measured level of the library is about 18 dB above the level in the depot, so the sound pressure there is 8 times (!) higher. The use of such a noise-absorbing chamber is a relatively simple and cost-effective solution to reduce the prevailing noise levels.

The effectiveness of the chamber was measured in the anechoic room of the Institute of Musicology at the University of Vienna (RT_{60}<20ms, LA_{eq}: 22dB). The recording chamber was placed in the room and one level meter was placed inside and one outside the chamber (Figs 7 and 8). In the room itself, a measurement speaker was used to generate a diffuse sound field with 1/f noise (also called pink noise), a measurement signal in which all frequencies in the spectrum are equally loud to the human ear. To determine the attenuation of the chamber, the level measured outside the chamber was compared with the level inside the chamber.

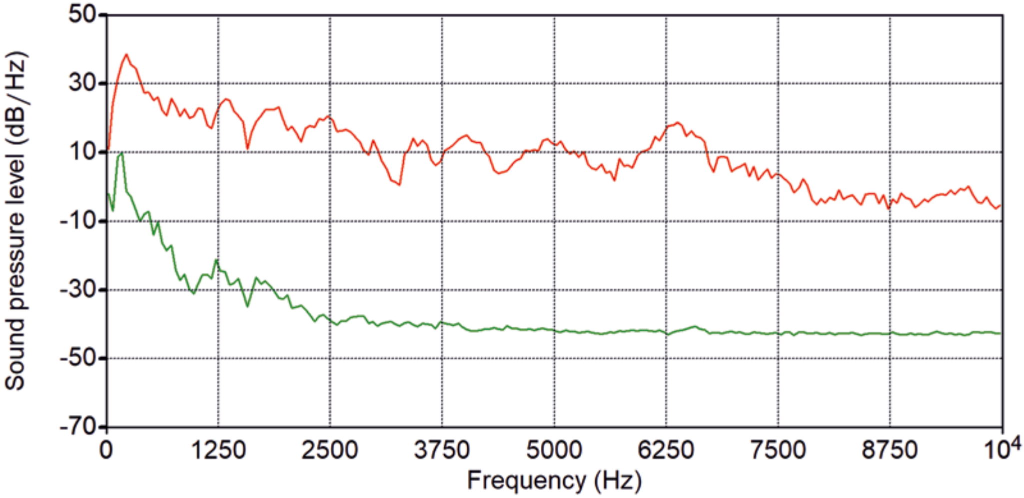

Fig. 9. Noise measurement spectra, red outside, green inside the chamber. FFT size 1024, Hann, graphic: Jörg Mühlhans.

Results, applications and discussion of possible acoustical problems

Measured linearly, the chamber shows a reduction in level of 13.9 dB. Since the chamber's insulating layer is only a few cm thick, the damping effect is rather weak in very low frequencies. However, since the musical instruments to be recorded are very high frequency, the A-weighting gives more information, since very low frequencies are filtered anyway during recording. In LAeq the level difference is 21.4 dB on average. Figure 9 shows the noise spectra inside and outside the chamber, which also shows that the damping effect increases with frequency and is even around 30–35 dB in the frequency range of the instruments to be recorded (Fig. 9). This proves that noise in the recordings can be significantly reduced. The measurement shows the simple level difference according to ISO 140-4, given as $D = L_1 - L_2$ (ISO 140, 1998), since there is no standard procedure to measure such a special construction.

Despite the positive effect, it must also be noted that the chamber itself is a Helmholtz resonator if the opening is not sealed by the arm protruding into the interior. The resonance frequency is 63.8 Hertz[7] if the opening is not sealed. In order not to falsify images, this resonance frequency must be avoided.

[7] $fres = \sqrt{(\pi * \frac{R^2}{V * \left(I + \left(\frac{\pi}{2R}\right)\right)})}$

A further problem could be the room modes that occur inside the chamber. Due to the dimensions, some modes below 1 kHz can be calculated (430, 570, 715, 810, 860 Hz)[8], but the absorption coefficient is already $\alpha > 0.95$ at 500 Hz. Thus, it can be assumed that modes do not have a disturbing influence on recordings, but the possibility should be taken into account.

Experiences in using the sound reduced chamber in museums

Sound recordings have already been made in the following institutions as part of the research project: in the Vasi Múzeum Látványtár in Szombathely, Hungary, where the archaeological collection of the Savaria Museum is located, in the Podunajské múzeum, Komarno, Slovakia, in the picture library, in the Magyar Nemzeti Múzeum Budapest, Hungary, in a small drawing room on the top floor of the museum, where a second person was drawing, in the Slovenské národné múzeum Bratislava, Slovakia, in the meeting room next to the secretariat. This room had only simple windows and all the noise of the Danube bank road could be heard, as well as every conversation in the secretariat. We also did sound recordings in the Stadtmuseum Wels in Austria, which resides in an abandoned monastery and here specifically in an empty, small late gothic chapel with much reverberant sound. Last but not least, we should mention the "Eiszeit" depot of the Prehistoric Department in the Natural History Museum Vienna, where two or three people work at the same time.

Conclusions

A portable noise-absorbing recording chamber offers an optimal solution for sound recordings of archaeological idiophones in museum rooms. The box, made of lightweight poplar plywood and a double insulation layer of Rockfon Facett Plano 20 mm panels, weighs 7 kg and can be transported on a modified shopping trolley. Even though the insulation cannot protect recordings from very low frequency noise, it is still quite sufficient for mid and high frequencies with a dampening effect of 21.4 dB on average. Low frequency noise can be dealt with using a high pass filter. The use of such a noise-absorbing chamber is a relatively simple and cost-effective solution for reducing background noise when recordings have to be made in noisy environments.

[8] Room modes occur when the wavelength of a frequency or its multiples coincide with the distance between opposing surfaces in a volume.

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