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Schallmauer: Composing Tactile Sound for the Solid Medium

Keywords: Sound Installation; Sonic Interaction Design; Tactile Sound; Acoustic Architecture.

Abstract:

In this article we describe the *Schallmauer*, a site-specific interactive sound installation at the new *Musiktheater* opera house in Linz, Austria. This installation explores the tactile qualities of musical composition and interactive sound, while invisibly integrating into the existing architecture of the building. The installation reacts to the presence of the bypassing audience, intending to attract their attention and motivating further explorative interaction. Through a series of interactive infrasound compositions, it emphasizes the experience of sound within the solid medium of a wooden wall and beyond, which expands the predominant auditory and visual impressions of an Opera House by directing the focus to the listening through the body. Apart from the conceptual and technical background of this project, we also present some relevant related artworks in the area of tactile sound interaction and composition.

1. INTRODUCTION: MUSIC FOR THE TACTILE MEDIUM

As we listen to music, we often find ourselves also bodily feeling the sound, the embodied perception of sound is cross-modal. Besides the auditory perception, physical sound also stimulates the proprioceptive, vestibular, and/or tactile cutaneous afferents from the somatosensory system (Huang 2013). The sensory cortex, separated from the auditory cortex, is the part of the brain that recognizes tactile, or touch, feedback. We know that deaf people are not able to hear sound but they are able to feel it and even to recognize songs (Livadas, 2011). The vibrotactile aspect of music is also crucial in achieving immersive experiences. For this reason, various human computer interaction devices enhance entertainment within media (Saddick 2007) through vibrotactile stimulation: video-game gamepads with haptic feedback, cinema seats with body shakers, etc. Taking this particular dimension of music into consideration, the art installation we are presenting extensively uses vibration for creating a vibrotactile soundscape within an architectural space.

The *Schallmauer* (the German word for "sonic wall", stands at the same time for "sound barrier") is a large-scale interactive sound installation exploring the possibilities of composing sound for the tactile medium. The project origins from a commission from the new *Musiktheater* opera house in the city of Linz, Austria for transforming a long neutral corridor into a space for musical interaction. Our artistic proposal was the production of an interactive installation where visitors could actively experience a series of compositions through their whole bodies. The *Schallmauer* incorporates a large number of sound transducers, sensors and single board computers featuring a simple and modular hardware and open source software system that can be re-implemented by others.

Sound transducers are acoustic drives that are able to turn almost any solid surface or object into a speaker. Being essentially like any other standard aerial speakers, their coil is not attached to a cone, but is fixed to a pad conducting its vibration onto the object it is attached to. The resulting resonance disperses as a flat field through its surface producing the sensation that the whole surface emits sound. By attenuating some frequencies and amplifying others, these resonating objects act like natural filters adding their particular acoustic profile to the reproduced sound.

Using these devices, sound also becomes graspable through vibrotactile perception if we keep a physical contact with these vibrating objects and its surfaces. In Human-Computer Interaction, early studies of this phenomenon dates back to the 1920s when Gault created machines for transferring speech into vibrotactile stimuli (Gault 1924). More recently, the growing field of multimodal human-computer interfaces has established the basis for presenting haptic information to users using tactile and kinesthetic devices (Saddik, Chouvardas et al, Eid et al 2007).

The use of sound transducers in media art and music is also not recent. According to John Driscoll (Driscoll 2001), sound transducers became commercially available during the decade of the 1960s and descended from a design developed for underwater speakers used by the US Navy. In June 1966, the "Popular Mechanics" magazine described to the home hobbyist how to "Build a FANTASTIC CONELESS LOUDSPEAKER!". Interestingly, among the papers found at David Tudor's workshop, a copy of this magazine was found. In particular, David Tudor employed sound transducers attached to radio-controlled carts in his work *Bandoneon!* (1966) and later at *Rainforest* (1968) where transducers affixed to everyday objects caused them to resonate. In Laurie Anderson's *The Handphone Table* (1978), the viewer's elbows touching two transducers serve as conductors for listening the otherwise inaudible sound. This is also an example of bone conduction, the conduction of sound to the inner ear through the skeleton and skull bones. Markus Kison's *Touched Echo* (2007-2009) uses the same technology for conducting sounds of cities devastated during the Second World War through the arms of the visitors. Carola Bauckholt's composition *Doppelbelichtung*

(2016) illustrates a recent musical application of sound transducers. It is a composition for one violinist and five other violins hanging in the air and equipped with tactile transducers. The reproduction of nature sounds through these transducers make the recordings acquire the spectral characteristics of a violin. Vibrotactile communication has been extensively employed in media art. For instance, Kaffe Matthews' *Sonic Bed* (2005) and Satoshi Morita's *Sound Capsule* (2014) stimulate the visitor's whole body creating a dynamic, multi-sensory approach to experiencing music. In Juri Hwang's *Somatic Echo* (2017) listeners experience a sonic image shaped by sounds traveling through their head structure and through vibrations applied to their skin. In conclusion, all these works let us experience sound through our skin, but they also make us aware of our body through sound. Captions of these works can be observed at Figures 1.1. to 1.3..

Vibrating surfaces can be also used to create immersive spatial or architectural installations. The key concept here is turning the found objects of an architectural space into sound sources. These vibrating soundscapes augment spatial architecture towards the aural and the vibrotactile level. For instance, Otso Lähdeoja and Lenka Novakova's *OVAL* (Lähdeoja 2014) is a large installation where ten large sheets of glass equipped with transducers are hanged forming an oval inside of a dark room. The work creates a spatial polyphony of aurally active glass sheets designed to warp visitor's perception of sound in space. Using a tracking system, the installation changes its musical content depending on the location of the audience.

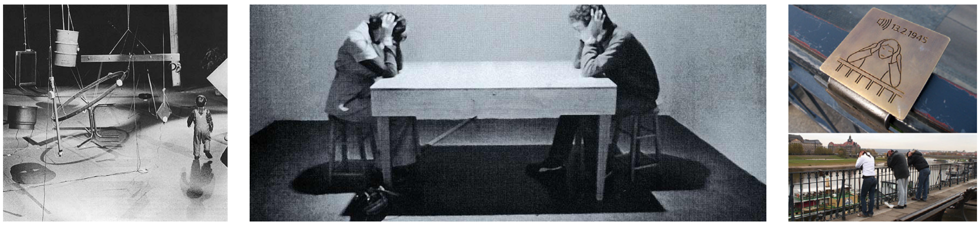


Fig. 1.1. Tudor's *Rainforest*, Anderson's *Handphone-Table*, Kison's *Touched Echo*.

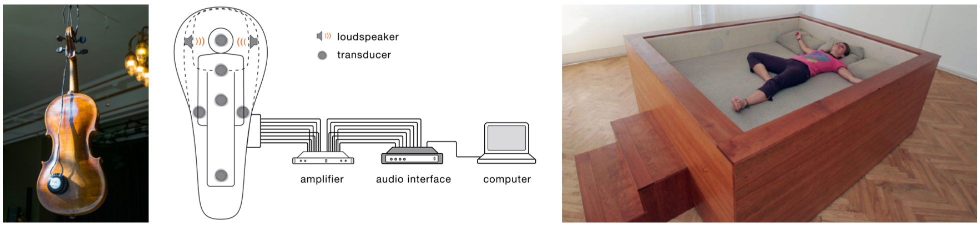


Fig. 1.2. Bauckholt's *Doppelbelichtung*, Morita's *Sound Capsule* and Matthews' *Sonic-Bed*.

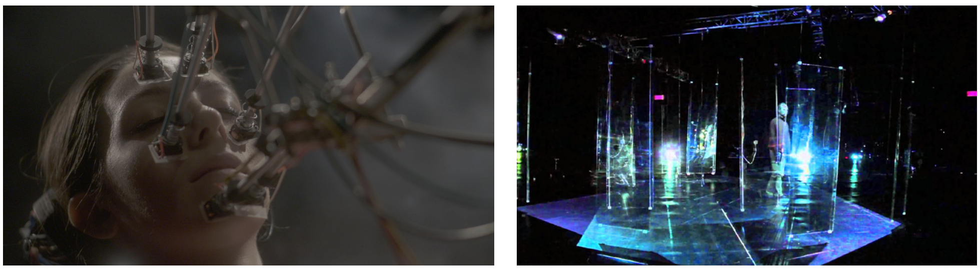


Fig. 1.3. Hwang's *Somatic Echo* and Lähdeoja & Novakova's *OVAL*.

2. THE SCHALLMAUER INSTALLATION

Our design intention was the creation of an interactive medium for exploring tactile communication. Thus, the installation is not only conceived as a space for contemplation but also a place for interaction. Audiences had to have the power to transform sound through touching actions while at the same time, they would also feel the installation with their bodies.

2.1. Artistic Intention and Design Description

The Schallmauer was commissioned by the Musiktheater Linz, the new opera house designed by Terry Pawson which was inaugurated in April 2013. The theatre management wanted to incorporate a new sound installation into the *Klangfoyer*, a large vestibule decorating the building with various contemporary artworks. The space dedicated to the installation would be the long corridor between the concert hall entrances of the second floor of the building. It is a roughly 30-meter long straight corridor defined by large wooden panels on the concert hall side, while the other side is open and communicates visually with the rest of the foyer (see Figure 2.1.). While this space would remain empty during most of the day, it would be crowded by the audience before and after an opera or concert performance. The management also was planning guided tours for groups up to 40 persons.

The conceptual proposal we presented to the theatre followed these design patterns:

- Architectural neutrality: The Schallmauer would be only represented through sound, no other significant visual design should be added.
- Interaction: audience and artwork should mutually interact, not only contemplated.
- Scale: interaction should be possible for a single person and for a group at the same time.
- Activity: the Schallmauer would remain silent if nobody is present at the corridor.
- Sonic identity: the musical content would be inspired by sounds from the city of Linz.

At the technical level we sketched the following ideas:

- The corridor should be understood as a unidimensional array of sound sources along its full extension. We were interested in creating a linear spatialization system which would feature listening to sounds moving at the distance, approaching and leaving, all along one only axis.
- The Schallmauer would incorporate sound transducers to produce vibrotactile sound through the wall itself, from infrasonic vibrotactile frequencies to the audible domain.
- As the corridor was subdivided into fourteen pieces of wooden panels along the distance, a modular system would be designed following these separations.
- Interaction would be based on the visitor location within the corridor, as well as the audience touching the wooden panels.
- The work would have different stages of interaction depending on audience activity.
- Open Source: we decided to use only open hardware and software technologies.

The theatre accepted our proposal in late 2013. A budget was negotiated and the opening date was fixed for September 2014. As it was impossible to develop the work directly at the corridor, we created an initial prototype at the Kunstuniversität Linz.

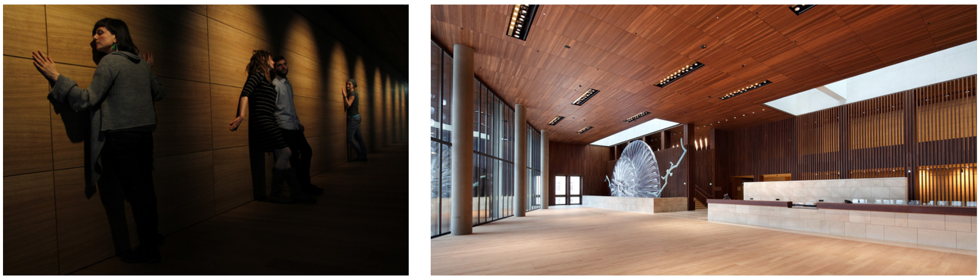


Fig. 2.1. The Schallmauer (left) in the Klangfoyer (right) of the Musiktheater in Linz.

2.2. Vibrotactile Prototyping

We built a structure of four identic wooden panels in order to evaluate various transducers, to measure the resonant properties of the wooden panels and to test the interactive sensor system. This configuration also afforded the production of sound materials and inspired new interactions.

After searching for different type of transducers, we decided to use Sinuslive Bass Pump III (80 Watts, 4 Ohms) for low frequencies and Visaton EX 60 S (25Watts, 4 Ohms) for medium and high frequencies. We also found the affordable four channels amplifier Basetech AP-4012 (4x50Watts) quite adequate, as it already incorporates low or high frequency filters to be used with our two different transducers.

For testing the resonance of the overall system, we built a simple apparatus. A computer reproduced a slow frequency sweep from 1 Hz to 20KHz through the transducers. A reference aerial microphone and another contact microphone attached to the panels were used to record the resulting sound response. A frequency analysis of these recordings clarified that our mechanical system had two critical resonant bands (15-21Hz and 35-39Hz) where the panels started to resonate in a very intense and possibly dangerous way. As we also wanted to work and play with these particular frequency bands, we decided to incorporate a digital filter to our system, which flattened these resonances.

We also discovered that the performance of the mechanical system radically depended on the physical junctions between the wooden panels and the supporting wooden frame. The substantial part of the vibrotactile content had to be dampened accordingly, and we experimented with combination of silicones and textile to buffer the vibration at these junctions.

2.3. Technical Description and Architecture

The 25m-long relevant portion of the wooden wall on the top floor of the Klangfoyer has been divided into a total of 14 segments, each of which is comprised of four wooden panels with a size of 176x62cm each. Omitting the bottom and top panels, we converted the total of 28 conveniently reachable panels (as a matrix of 14x2) into the active components of our interactive sound installation. We first removed the complete wooden assembly and attached all interactive components such as speakers and touch sensors to the back of each panel, while the single board computes, amplifiers and power supplies were attached onto the wall behind the top panel. Once reassembled this resulted in a completely unaltered appearance of the original wall, with the exception of barely visible motion sensors on the top of each vertical segment. 14 independent single board computers and a total of 56 contact speakers (two on each interactive panel, ergo four per segment) represent the elements of a modular multi-channel installation for tactile sound. Each of the 28 interactive wooden panels is equipped with six capacitive contact sensors, which allows to control the installation through a total of 168 segments touched by the hands and body. The 14 motion sensors that are distributed throughout the length of the corridor allow to detect the presence and motion of the visitors.

2.3.1. Hardware Components

As described above, the installation is divided into 14 equally designed segments, which are practically scalable to any number, but in this case defined the actual configuration of the corridor. Each segment consists of two wooden panels as the interactive component for sound reproduction and user interaction, as well as an additional control unit, containing a first generation Raspberry PI single board computer (SBC) (single ARM core, Model B), the four-channel Basetech AP-4012 amplifier as well as a suitable 12V power supply and a 5V converter for the SBC. Although the overall sound quality of the first-generation Model B computers was rather limited, we used the direct Stereo output from the SBC connected to the four-channel amplifier through a simple headphone splitter, instead of a dedicated multi-channel sound card. The built-in high/low frequency filters of our amplifier effectively allowed us to drive the two low-frequency Bass Pump transducers as well as the two high-frequency Visatone transducers with the simple stereo signal from the SBC.

A high/low frequency assembly of these transducers was firmly screwed onto a small wood and metal board sandwich, which was then glued to the centre of each wooden panel. In addition to that, the full back area of each panel was covered with six segments of large aluminium sheets, which served as capacitive touch electrodes. These electrodes were connected to a MPR121 touch sensor, which provides a total of 12 sensor pins (six for two panels). This sensor breakout board provides the according touch interaction states to the SBC through the I2C bus. In addition to the touch interaction the system is also detecting the presence of a visitor standing in front of a segment through a simple analogue PIR motion sensor attached to the ceiling above.

As a modular installation, the overall composition was controlled by one additional Raspberry Pi SBC, which maintained a global view of the user interactions within the corridor, which determined the general states and behaviours of the installation. This master computer was connected to the remaining 14 segments through Ethernet, and also provided an additional WIFI access point for control and configuration purposes as well as a 3G modem for remote control and monitoring.

Fig. 2.2. Background view of an interactive panel: dual transducer assembly and six touch electrodes.

2.3.2. Software Components

As its overall computing infrastructure is based on the Raspberry Pi SBC, the software architecture of the Schallmauer installation is also based on the Linux operating system. We therefore used a standard Raspbian distribution with a custom real-time Kernel in order to achieve an acceptable performance with the limited resources of the first-generation model B. For the sound synthesis and playback, we used optimized builds of the Pure Data (Puckette 1996) sound programming environment as well as the Jack audio server, which resulted in a perfectly usable software configuration for our purposes.

For the acquisition of the user interaction data from the touch and motion sensors, we developed a simple background application keeping track of the current touch states and user presence at each panel and segment. The resulting overall state updates were continuously broadcasted using *Open Sound Control* (OSC) (Wright et.al. 2003) to all other segments as well as to the master computer. The master computer processed the OSC input from all interactions at the individual segments, in order to determine the global state of the installation. Global state changes were then also communicated to the segment computers via OSC, which adapted their local program accordingly.

The whole system was configured to boot automatically into a functional state, which was indicated by an individual start-up beep from each system segment as well as a finalizing welcome tune controlled by the master computer. In this general interactive state, the system is ready to respond to the visitor presence and interactions, which largely determine the states and behaviours of the Schallmauer installation. In addition to that, we also provide a simple web-based control interface, which can be configured through a mobile phone connected via the integrated WIFI. This allows the overall maintenance and individual adjustments to the installation, such as the control of the global volume or the selection of dedicated behaviours or demonstration modes.

2.4. Interaction Design and Composition

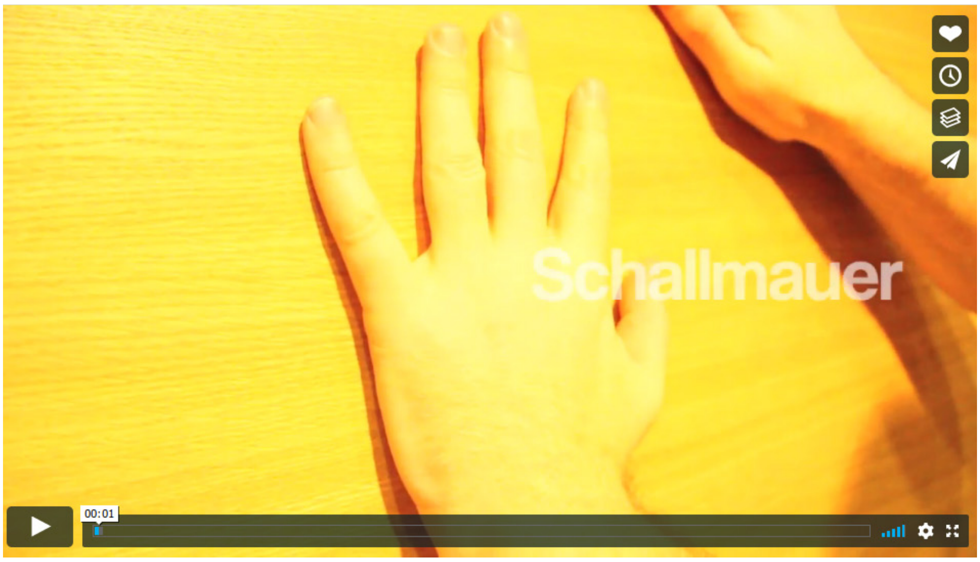
Since the Schallmauer is invisibly integrated into the existing architecture of the Klangfoyer corridor, it will generally remain silent when no audience is present. Once the presence of one or more bypassing visitors is detected by one of the lateral motion sensors the master computer is notified and subsequently switches the installation into *Attention Mode* in order to guide them into a dialogue with this interactive musical instrument. In this mode the Schallmauer intends to catch the attention of the bypassing visitor through the subtle playback of knocking sounds, as if someone would be knocking from the other side. If the visitor decides just to walk by without interacting, the installation would simply switch back into *Silent Mode* after losing track of any present visitor. If the visitor on the other hand would remain within the corridor, still being detected by one or more of the motion sensors, the installation would intensify the *Attraction Mode* by playing back silently whispering voices in addition to the occasional knocking sounds, which are following the path of the visitor.

As soon as the visitor would approach and eventually touch one of the interactive wall segments, the installation would immediately switch into *Interaction Mode*. In this mode each interactive panel would respond with the sound of creaking wood, which again in a similar manner as the knocking sounds would correspond to the wooden materiality of the corridor wall. In addition, the wall would start to play back several low frequency sweeps that are close to the resonant frequency of the wooden panels and therefore cause occasional strong vibrations when going through the location of the visitor.

If this encourages the visitor the further interact with the wooden panels, the installation would consequently switch into the final *Listening Mode*, which would play back one of the three infrasonic compositions, which we developed for this sound installation. These compositions represent the inner sounds of the city of Linz with a metaphorical arrangement of underwater sounds from the Danube, the industrial sounds from the steel factories, as well as the motion from the public transport system. All these compositions play with the sound vibrations through the solid medium of the wooden wall, which can be experienced by listening into the wall or just by touching the wall with the body.

If the visitor stops interacting with the wall, the installation would immediately switch back into *Attention Mode* and subsequently into *Silent Mode* if the visitor leaves the installation area. If the visitors decide to keep on playing with the installation after the playback of the first composition, they are rewarded with an interactive *Interlude Mode*, which basically turns the Schallmauer into a large scale interactive instrument, which plays low-frequency harmonic sounds for each of the individual touch segments on the full extension of the wooden panels. Alternatively, the Schallmauer can also be manually switched into a simple *Marimba Mode*, which again emphasizes the

Fig. 3. A video demonstration of the Schallmauer installation: https://vimeo.com/96206403.



wooden materiality of the corridor through the interactive playback of pitched wood sounds in a large-scale Marimba instrument.

2.5. Conclusion

As of today, the Schallmauer installation has been in continuous operation for almost five years at the Musiktheater in Linz, only interrupted by the occasional alternative use of the corridor for photo exhibitions. The overall software and hardware design has proven to be sufficiently stable for long-term usage, and only required occasional maintenance and updates so far. The compositions and the interaction design of the installation also have been very popular with the daily audience and the guided tours at the opera house. An analysis of log files of the installation revealed, that the visitors interacted as intended with the installation, and we can observe both the prolonged individual exploration of the infrasonic compositions, as well as the more ludic interactions of larger audiences.

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