# The Intrinsic Value of Timbre in *Doppelganger*

**Asbjørn Blokkum Flø**
Norwegian center for technology in music and the arts (NOTAM)
Sandakerveien 24D, Bygg F3 0473 Oslo, Norway
asbjorn@asbjornflo.net

**Hans Wilmers**
Norwegian center for technology in music and the arts (NOTAM)
Sandakerveien 24D, Bygg F3 0473 Oslo, Norway
hanswil@notam02.no

## ABSTRACT

*This paper presents the sound art installation* Doppelgänger *(2014). In* Doppelgänger*, we combine an artistic concept on a large scale with a high degree of control over timbre. The installation consists of seven 3.5 meters-tall objects weighing a total of 1500 kilos. The intrinsic value of timbre is central to this installation, and this is linked to the tradition of percussion music, experimental instrument-building and sound art.*

*Using scientific methods in the production of acoustic sound objects gives us a deeper understanding of timbre. We propose a method of simulating the timbre of the sound objects using models of plates and mallets. A source-filter model was created using Supercollider. In this model the excitation by the mallet is the source, and the transfer function of the metal plate is the filter. A sound recording of the acoustic sound objects was made. When the measurements from this recording are compared to the predicted resonances, most predicted resonances are near the measured resonances. This supports our model, and makes our findings applicable to other projects of a similar nature.*

## 1. INTRODUCTION

This text provides a description of the artistic and historical context of the installation *Doppelgänger* (2014), as well as presenting a model for modelling the timbre of the sound objects used in this installation. Little emphasis will be placed on the electronics and mechanics developed for this work. *Doppelgänger* is a large-scale sound installation that relocates one soundscape into another using audio analysis, mapping, and computer-controlled acoustic sound objects. Microphones are placed in the café next to the exhibition space. The sounds from the café are analyzed and then mapped to the computer-controlled acoustic sound objects. In this way the audience will experience the installation as an acoustic mirror of the social space that constitutes the café. *Doppelgänger* builds on the history of mechanical instruments, as well as computer-controlled acoustic musical instruments and sound art.



## 2. BACKGROUND

The earliest known design of a programmable machine is an automatic flute player that was described in the 9th century by the brothers Musa in Baghdad [1, 2]. Player pianos emerged and gained popularity during the last half of the 1800s, and these instruments reached a new level of precision in the 1970s with the introduction of computer-controlled electromechanical pianos [3]. Since then groups such as the Logos Foundation (1990-) have built large ensembles of computer-controlled acoustic instruments, greatly expanding the available types of instruments [4].

Beyond music written for computer-controlled acoustic instruments, there exists a practice of using computer-controlled acoustic sound objects in an art context. Here, concepts such as the ontological properties of sound, the use of space, and mapping of data sets are often more important than traditional musical ideas. The idea of examining a data set by mapping it to computer-controlled sound objects can be found in many works of sound art. One example is Peter Ablinger's ongoing work cycle *Quadraturen III ("Wirklichkeit")* (1996-), where a computer-controlled piano is used to resynthesize speech [5].

### 2.1 Relocation of Space

The mapping of a data set from one field to another is also an important element in the installation *Doppelgänger*. In this site-specific sound installation the sound of the café in an art museum is relocated into the exhibition space. Here the sound of the café is presented in processed, analyzed form - as an abstract, sonic shadow-version of the real world. Through *Doppelgänger's* relocation of space the auditory focus is shifted, and the hidden aspects of the social space appear. *Doppelgänger* becomes a shadow version of the real world, a place where concealed structures may emerge. The installation is also an examination of the acoustic character of the space. The sound experience of the café has a unique quality of its own, beyond language and meaning. This sonic dimension is examined in the installation through several computer-controlled acoustic sound objects surrounding the listener.

The relocation of space in *Doppelgänger* starts with audio analysis. Microphones pick up the sound of the café. This sound is analyzed in real time using FFT-based perceptual analysis, filters, and amplitude followers. The data from the analysis is then mapped to the sound objects using solenoid-actuated hammers beating on steel plates. The data from the audio analysis is mapped to different hammers and plates for a wide variety of timbres. Different layers of sounds operate within different stochastic distributions. The thresholds and superposition of these distributions add to the character and complexity of the installation.

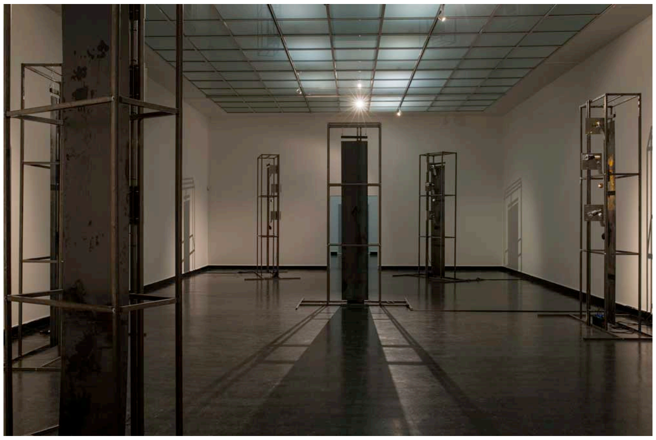

**Figure 1**. Computer-controlled acoustic sound objects surrounds the listener. Photo: Thor Brødreskift.

# 3. THE INTRINSIC VALUE OF TIMBRE

Together with the relocation of sound, the intrinsic value of timbre is central in *Doppelgänger*. In the installation these two concepts are living in a symbiotic relationship, where timbre emphasizes the relocation and the relocation in turn is projected on the timbre. This focus on the intrinsic value of timbre is an important constituent in many works of sound art. For sound artist Trimpin the artistic process always starts with the sound he wants to hear. It may be sounds of nature, urban sounds, or an acoustic phenomenon. It is only when the idea of the sound is established that it can be materialized as a work of art [6].

The idea of the intrinsic value of timbre has been part of experimental music throughout the 20th century. Already in the manifesto *The Art of Noises* (1913) Luigi Russolo draws attention to how noise timbres can free music from the traditional timbres of the orchestra. This continued in the second half of the 20th Century, where timbre was used to break free from traditional music musical thinking. In works such as *Threnody for the Victims of Hiroshima* (1960), *Lontano* (1967) and *Konx-Om-Pax* (1969) composers such as Krzysztof Penderecki, György Ligeti and Giacinto Scelsi went deep into the constituents of timbre. In *Partiels* (1975) composer Gérard Grisey went one step further and used computer analysis of timbre to create compositional models.

## 3.1 The All-Sound Music of the Future

The notion of investigating the constituents of timbre is central in *Doppelgänger*. The idea of complex sounds produced by free-hanging large metal plates arose early in the creative process. These sound objects have a complex sonic character and are closely related to classical percussion instruments. Most of the percussion instruments in classical music come from non-Western cultures and are therefore a relatively new phenomenon in western culture. It was Hector Berlioz (1803 - 1869) who first created a percussive ensemble within the larger symphonic orchestra. With Edgard Varèse's *Ionisation* (1929-1931) for 13 percussionists, the melodic instruments are almost completely gone and we are left with a music of timbres. Many composers have used percussion music as a way to break free from traditional western music, and in the text *The Future Of Music: Credo* (1937) John Cage describes percussion music as "*a contemporary transition from keyboard-influenced music to the all-sound music of the future.* " [7]

## 3.2 Free-Hanging Metal Objects

The complex sounds of free-hanging metal objects are central in *Doppelgänger*. If we investigate these timbres among traditional percussion instruments we discover that they have a number of interesting characteristics. Instruments such as the cymbal, tam-tam and gong are essentially flat circular plates. In a cymbal the low-frequency modes are fairly similar to those of a flat circular plate, but at higher frequencies more complex phenomena arise [8]. In tam-tams, the various partials build up with different delays, resulting in an interesting development of timbre over time. Gongs have a higher mass in the centre of the instrument. This results in an octave relationship between the first two partials and leads to the tonal character of this instrument. All these instruments are closely related to the sound objects in *Doppelgänger* both physically and in relation to timbre.

Another group of instruments in which the timbres are closely related to *Doppelgänger* are bells. Bell founders gradually discovered how they could tune the partials of the instrument harmonically and bell founder, musician and composer Jacob van Eyck (c. 1590-1657) concluded that the best bells had five partials tuned harmonically to the intervals octave, minor third, fifth and octave. These five intervals constitute the first five vibrational modes in a tuned bell.

Tubular bells have been widely used to produce a bell-like sound, and the tuning of partial 3 to 8 are very similar in tubular bells and regular bells. An interesting feature of tubular bells is that there is no vibration mode with a frequency on or near the pitch one hears. What we hear is a virtual pitch. Another example of instruments with bell-like timbre are bell plates. These are rectangular metal plates with a length-to-width ratio of approximately $L/W = \sqrt{2}$ (=1,41). They have two partials approximately an octave below and above the fundamental. In addition to these harmonic partials bell plates have several strong partials that have a more complex relationship to the fundamental. Bell plates is the instrument that comes closest to the sound objects in *Doppelgänger* both in sound and design. Unlike the steel plates in *Doppelgänger,* they are usually made of aluminium or bronze and on a much smaller scale. Common to all free-hanging traditional percussion instruments in metal is that they have spectra that are significantly different from those that are found in traditional melodic instruments.

### 3.3 Experimental Sound Objects

Complex modes, delays of partials and virtual pitch are some of the many interesting aspects of free-hanging traditional percussion instruments in metal, and they coincide with the notion of timbre that underlies *Doppelgänger*. But if the idea is to shape the sound of percussive sound objects according to an artistic concept, the field of experimental acoustic instruments should be examined.

An early example of experimental instruments is Luigi Russolo's *Intonarumori* (about 1910-1930), which consists of a group of 27 instruments focused on noise sounds. Engineer Bernard Baschet and sculptor François Baschet had a more scientific approach and built a variety of instruments based on acoustic phenomena. The most famous is perhaps *The Cristal Baschet* (1952), where sound is produced by friction against glass rods mounted on metal rods, amplified by metal bars and resonating plates.

When it comes to the construction of experimental percussion instruments, the theorist, composer and instrument maker Harry Partch (1901-1974) is in a category by himself. In a period extending more than 40 years Partch composed music for his custom-made instruments based on his own theory of music described in the book *Genesis of a Music* (1947). Many of his percussion instruments are marimba-style instruments built with microtonality in mind, but he also made percussion instruments that explored new timbres such as the *Cloud Chamber Bowls* (1950) and *Cone Gongs* (1964).

The development of experimental percussion instruments still takes place and instruments such as the *Water Phone* (1975) *Sound Pyramid* (2000), *Hang* (2001), *HAPI Drum* (2008) and *Gubal* (2013), combine instrument-making with scientific methods, acoustics and new materials [9].

## 4. COMPUTER-CONTROLLED SOUND OBJECTS

The field of experimental percussion instruments is a central source of inspiration for *Doppelgänger*. Through the production of experimental percussion instruments the possibilities of timbre and music have been expanded. Put under computer control, these acoustic sound objects can go beyond what is humanly possible. Since the introduction of computer-controlled electromechanical instruments in the 1970s, numerous computer-controlled percussion instruments have been made. Several of these are computer-controlled traditional percussion instruments like the vibraphone *Vibia* (2001-2010) [4], the xylophone *XyloBot* (2006) [10] and the glockenspiel *Glockenbot* (2010) [11]. Beyond these computer-controlled traditional percussion instruments there are several new instruments that cannot be easily categorized. In these instruments new sound sources are combined with sculptural design. The *Heliphon* (2004) [12] is a double helix shaped metallophone that use solenoids to play on metal bars. In Trimpins works *Conloninpurple* (1997) [6], a large number of computer-controlled, solenoid actuated marimba bars with resonators are freely hanging from the ceiling, creating a three-dimensional sound space.

### 4.1 Concept and Timbre

Beyond music written for computer-controlled percussion instruments, there exists a practice of using computer-controlled acoustic sound objects in an art context. The boundary between music and visual art is often blurred in sound art, and Felix Hess' installation *It's In The Air* (1996) contains no sound at all. A room is filled with hundreds of small flags made of Japanese rice paper which balance close to the floor and visualize whirlpools, movements and air pressure fluctuations that occur at the micro level in the exhibition space. One can nevertheless interpret this work within a sound art context as a metaphor for sound, and listening as an exercise in sensitivity [13].

Several works of sound art examine such distributed mass events in space. In Bosch & Simons *Cantans un Huevo* (2000-2001), an oscillating motor causes glass bottles to rattle against each other. The bottles are placed on springs, and the combination of motors, springs, bottles and distribution in space, creates a complex oscillating system of percussive sounds. Since 2006, the artist Zimoun has created a variety of sound installations in the form of architectural interventions and sound sculptures. Percussive sound sources produced by DC motors and cardboard boxes are frequently used. Because Zimoun's works usually consist of large amounts of uniform objects distributed in space, the spatial element attracts special attention. Although these works consist of percussive timbres they are not composed timbres in the traditional sense. These spatial mass events occur in the border area between concept and timbre. It is within this very same area that *Doppelgänger* operates.

### 4.2 An Acoustic Model for Sound Art

The sound of the free-han ging metal objects was central to the creative process in *Doppelgänger*. To get a deeper understanding of timbre we must understand the mechanisms that create it. Through audio analysis, acoustic models and sound synthesis we increase our insight into these mechanisms. By using scientific methods in the production of experimental acoustic sound objects, it is possible to achieve the same detailed control over the spectrum that otherwise could only be found in electronic music. No acoustic model can simulate all the details of a complex metal sound. But an understanding of the acoustic principles behind the materials and the shape of the object, provides a better understanding of the artistic possibilities. If we can control the partials of the sound object we can use this in the artistic work, controlling such things as the sound objects degree of dissonance, consonance and spectral relationship.

The starting point for *Doppelgänger* is a rectangular plate with four free edges, namely a free-hanging narrow steel plate. The acoustic model for this plate has a set of simple input parameters. The material is defined by its density, stiffness and damping factor. The density and stiffness affects the location of the partials in the spectrum. The damping factor determines the spectral envelope over time. In this way we can easily simulate materials such as steel, aluminium or bronze. This gives the artist the opportunity to do detailed investigations of the differences in timbre between various materials.

**Figure 2**. The starting point for Doppelgänger is a rectangular plate with four free edges. Photo: Thor Brødreskift.

The dimensions of the plates have a big impact on the timbre. The thickness provides a linear increase of the frequencies. A plate twice as thick will have a spectrum that is an octave higher. The acoustic model also contains three sets of modal frequencies. One for the length of the plate, one for the width and one set that is a result of both length and width.

In *Doppelgänger,* all plates are 3 meters long, and the only thing that is varied is the width and thickness. The thickness of the plates varies between 3 and 5 mm, which produces a very low fundamental of between 1.8 and 3 Hz. With a thickness of for example 3 mm we do not have any frequencies within the limits of human hearing until we reach the sixth partial. The sound we hear from the plates consists of partials far up in the spectrum.

The width of the plates varies between 40 and 76.5 cm. The lowest modal frequencies of the width are between 64.4 to 167.73 Hz and are well within the limits of human hearing.

The modal frequencies of the length and width of the plate are combined into a third set of modal frequencies. These frequencies appear as clusters of resonance frequencies just above the modal frequencies of the width, and are very defining for what we perceive as the timbre of the sound objects. Through varying the width of the plate we can move these clusters up and down in the frequency range and in this way create varied and complex timbres.

The objects used to hit the plates have a big impact on the final timbre. The mass, shape and stiffness of this object defines much of the overall sound. A small, lightweight and hard object will emphasize high frequencies, while a large, heavy and soft object puts an emphasis on low frequencies. Although the resulting timbres sound very different we always hear the same set of partials, only with different weighting of the amplitudes. This can be compared to a filter, and by selecting which object is used to hit the plates different parts of the spectrum can be highlighted based on artistic choices.

The acoustic model for the sound objects in *Doppelgänger* shows us that with a set of simple input parameters we can create great variations in timbre. With these parameters we can shape timbre in an artistically interesting way. The model is a simplification compared to the acoustic reality but accurate enough for the artist to get an increased understanding of timbre as well as a basis for examining ideas before translating them into physical objects. The model also has a practical element. Production of these monumental sound objects is demanding both physically and in terms of financing. It is therefore a major benefit to be able to simulate these sounds before starting the physical construction of the sound objects. To simulate these timbres we must turn to the acoustics of resonating plates.

## 5. THE ACOUSTICS OF RESONATING PLATES

Vibrations of plates have been described many times in the acoustic literature. Of special importance are the early discoveries of Chladni [14], who described nodal patterns formed by sand on vibrating plates. An extensive discussion of later investigations is given by Leissa [15], and a systematic collection of physical explanations by Fletcher and Rossing [8]. For some cases of plates with supported edges, exact solutions for the resonance frequencies are known. However, for the case of the rectangular plate with 4 free edges, the resonances can only be approximated, or simulated numerically. Methods that also take nonlinear oscillations into account are shown by Bilbao [16], and by Ducceschi [17]. However, most results given in above publications are for specific length/width ratios, and are not suitable for the rather narrow plates used in *Doppelgänger*.

Here, another model is proposed for narrow rectangular plates, that does not claim physical correctness nor precise results. Instead, the model will be simplified so that it is very easy to calculate. We will see later that for the plates used in this project, it still gives a good prediction of the most important resonances and of reverberation times.

### 5.1 A simple Prediction Model

The 7 resonating plates used in *Doppelgänger* are made of steel, and have different physical dimensions (See Table 1).

| Plate | Length | Width | Thickness | Weight |
|---|---|---|---|---|
| Plate 0 | 3 m | 0.5 m | 3 mm | 35 kg |
| Plate 1 | 3 m | 0.6 m | 4 mm | 57 kg |
| Plate 2 | 3 m | 0.6 m | 3 mm | 42 kg |
| Plate 3 | 3 m | 0.765 m | 5 mm | 90 kg |
| Plate 4 | 3 m | 0.4 m | 5 mm | 47 kg |
| Plate 5 | 3 m | 0.6 m | 5 mm | 71 kg |
| Plate 6 | 3 m | 0.4 m | 4 mm | 38 kg |

**Table 1.** Physical Dimensions of the Plates

The plates are hung from wires in a way that allows displacement perpendicular to the surface. The physical model for this is a rectangular plate with 4 free edges [8].

The rectangular plate with 4 free edges has curved nodal lines, with increasing irregularity for the higher modes. However, with increasing length-width ratio the plate will eventually converge to a rectangular bar, and the modal frequencies in one direction can be approximated by bar resonances. In the other direction, this would produce bigger errors, but with decreasing width these resonances will increase in frequency, so that only the first few modes, with less curvature, will be of importance. Under the assumption that it is so, the modal frequencies for both directions can be calculated as the bending modes of the thin bar, as given by Fletcher and Rossing [8]. For a plate with length L, width W and thickness h, this leads to following modal frequencies:

$$f_m = \frac{0.113h}{L^2}\sqrt{\frac{E}{\rho}}\left[3.0112^2, 5, \ldots, (2n+1)^2\right] \quad (1)$$

$$f_n = \frac{0.113h}{W^2}\sqrt{\frac{E}{\rho}}\left[3.0112^2, 5, \ldots, (2n+1)^2\right] \quad (2)$$

with

$E$ = Young´s Modulus

$\rho$ = Density

Modes with nodal lines in both main directions do not have a simple solution. However, for a plate with simply supported edges, the contributions to resonance frequency from the number of node lines in the two main directions simply add up. This can be seen in this formula given by Fletcher and Rossing [8] for the plate with simply supported edges:

$$f_{mn} = 0.453\, C_L h\left[\left(\frac{m+1}{L}\right)^2 + \left(\frac{n+1}{W}\right)^2\right] \quad (3)$$

with:

$C_L$ = *longitudinal wave velocity*

This leads to the following simplification for mixed modal frequencies:

$$f_{mn} = f_m + f_n \quad (4)$$

This set of modes is a rather rough simplification, as other modes and combinations of modal patterns are known to exist [14, 8]. Also, the influence of Poisson's ratio is not considered in this calculation. However, for an estimate of the acoustic properties, this simple model already gives valuable information.

It is worth to notice that the frequency ratios are independent of material properties. All frequencies will thus be scaled with the same factor, if the material is changed but the physical dimensions remain the same.

### 5.2 Excitation Method

In *Doppelgänger*, three different types of mallets are used to hit each plate: A steel mallet, a wooden mallet, and a wooden mallet covered with wool.

The mallets are accelerated by a mechanism driven by solenoids. Three different types of mechanism are used, and two types of solenoid, depending on the mallet type.

The solenoids are fed using PWM of varying length and ratio. The usable dynamic range was ca. 25dB.

### 5.3 Source-Filter Model

A digital model of the prediction algorithm was implemented in SuperCollider[1] as a source-filter model.

In a source-filter model of the resonating plates, the excitation by the mallet will take the role of the source, and the transfer function of the metal plate will take the role of the filter. If both of these are known (or can be calculated), the model can be constructed by convolving the source signal with the impulse response of the filter.

The model consists of an excitation pattern simulating the mallet, which is then convolved with a theoretical impulse response. (See Figure 3)

[1]http://supercollider.sourceforge.net

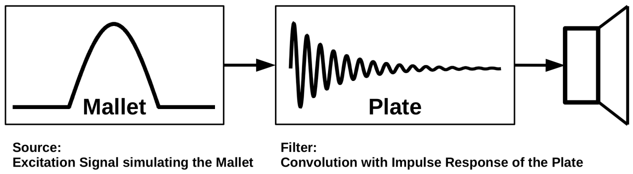


**Figure 3**. Source-filter model of a *Doppelgänger* plate.

### 5.4 Modelling the plates

The metal plates are modelled by an array of damped harmonic oscillators of the form:

$$x(t) = a\sin(\omega t)e^{(-\gamma t)} \quad (5)$$

with

$a$ = *start amplitude*
$\omega$ = *angular frequency*
$\gamma$ = *damping factor*

To find the right damping factor, it is assumed that these sources of damping exist:

- damping through sound radiation
- damping through friction within the metal plate

Internal friction in metal alloys results in a flexual loss factor Q that is material dependent and shows little or no frequency dependence at room temperature [18]. Flexual loss factors to calibrate the model were gathered from Irvine[2].

To simplify further, it is assumed that damping through internal friction is dominant, so that damping through sound radiation can be represented by a constant. For sufficiently small damping ratios, each oscillator can then be written as:

$$x(t) = a\sin(\omega t)e^{(-\gamma t)} \quad (6)$$

with

$a$ = *start amplitude*
$\omega = 2\pi f$
$\gamma = d_s + d_f f$

and

$d_s$ = *damping through sound radiation*

$d_f$ = *damping through internal friction*

The response of this oscillator to an acceleration impulse will also be a damped sine wave, starting at zero displacement:

$$g(t) = a\sin(\omega t)e^{(-\gamma t)} \quad (7)$$

The damping factor is thus depending only on the choice of material and the frequency, and increases monotonically with frequency. It will be shown below that this does not explain fully the timbre of the metal plates, but that it is a good approximation for a short time span after impact.

[2] *www.vibrationdata.com/tutorials/damping.pdf*

### 5.5 Modeling the Mallets

The action of the mallet hitting the plate can be explained by a partially elastic collision between objects with very different weight. The elastic collision can be modeled as a weight bouncing on a spring. The resulting acceleration pattern is a half-sine wave (See Figure 4).

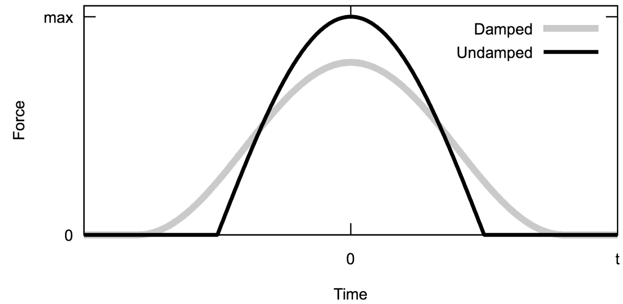


**Figure 4**. An idealised mallet during impact.

In fact, similar patterns are found by Wagner [19] for the interaction between drumstick and skin.

If the mallet is covered by a soft material, the edges at the beginning and the end of the impact will be rounded, changing the spectral characteristics of the impact (See Figure 5). In addition, absorption of energy and motion of the plate can cause an asymmetry in the acceleration pattern.

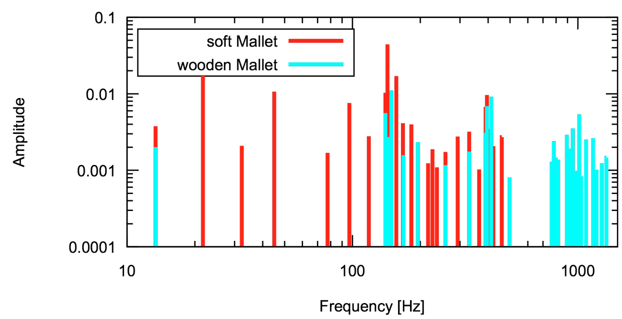


**Figure 5**. Plate 6, resonances measured 3s after impact.

### 5.6 Evaluation of the Model

Sound recordings of several plates with various mallets were analysed, and the dominant peaks in the spectre calculated using Audiosculpt at 3s after the impact.

It can be seen that the lowest partials are predicted with only small errors, and that the ensemble of frequencies $f_{mn}$ leads to a clustering of resonance frequencies right above each of $f_n$ (see Figure 6).

Incidentally, these are also the areas where listeners to recordings of the plates identify resonances that define the timbre.

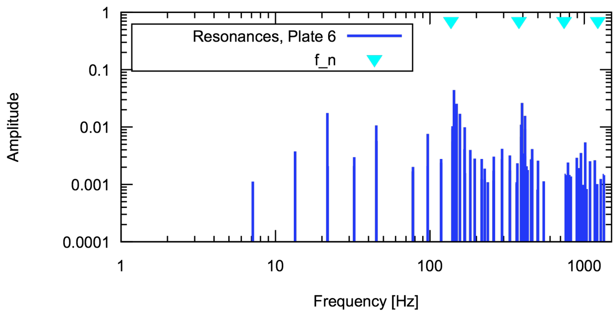


**Figure 6**. Plate 6, measured resonances. A cluster of Resonances occurs above each of the predicted f_n.

A comparison of measurements with predicted $f_{mn}$ can be seen in Figures 7 and 8 for two different plates that differ only in thickness.

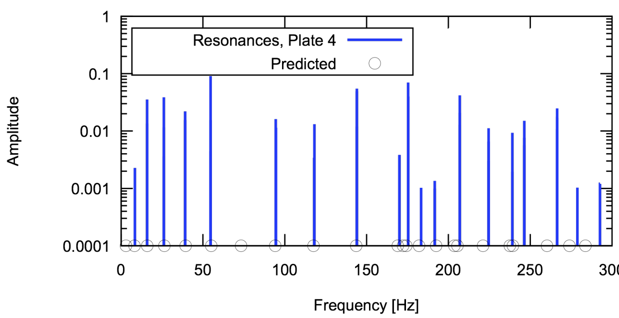


**Figure 7**. Plate 4, measured and predicted resonances.

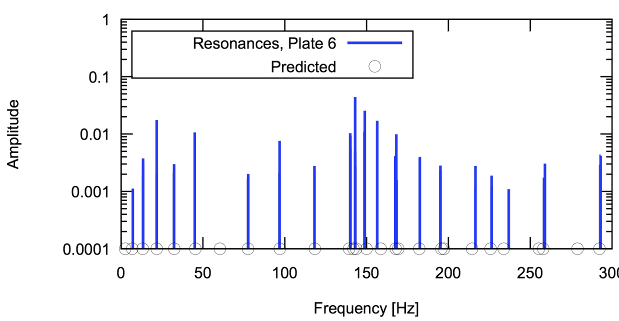


**Figure 8**. Plate 6, measured and predicted resonances.

One can see that most predicted resonances are near measured resonances. For plate 6, the values are corrected for a systematic error of 3%, which is inside tolerances of the input data to the model. The 7$^{th}$ partial is missing in both measurements, but it can be seen in the spectrogram of a recording (Figure 9) that it is indeed present for a short time after impact, at a frequency of ca. 60Hz.

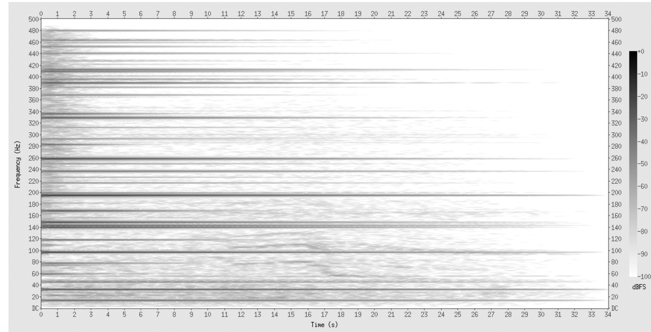

**Figure 9**. Plate 6, Spectrogram of a recording.

In the same spectrogram, one can see that many resonances decay much slower than predicted. This corresponds to the fact that the simulation of the same plate "sounds right" a short time after impact, but the characteristic timbre of the metal plate is not simulated correctly. So why is that?

As described by Rossing for the tam-tam, energy transfer between vibration modes leads to a slow buildup of higher frequency modes, giving the instrument its distinctive timbre [20]. A plate model using a finite differences scheme is described by Bilbao [16], which simulates the timbre of struck metal plates depending on the velocity of the strike, using nonlinear oscillations. Through harmonics of the nonlinear oscillations, energy can be transferred to oscillators with a higher fundamental frequency. These effects are not implemented in the model presented here, and this is why the decay of some resonances is overestimated. It would be desirable to include an explanation for this kind of energy transfer between modes, so that the timbre could not only be deducted from the ensemble of resonance frequencies, but could also be heard correctly in the simulation.

The prediction model described so far is deliberately kept simple. The only variables are the dimensions of the plates and physical properties of the material, namely the Young's modulus, density and flexual loss factor. It should therefore be equally valid for other materials, if these properties are given correctly. This makes it an easy-to-use alternative to other known methods to predict the sound character of free hanging vibrating plates.

## 6. CONCLUSION

In the sound art project *Doppelgänger*, we combine an artistic concept on a large scale with a high degree of control over timbre. The intrinsic value of timbre is important in *Doppelgänger*, as in the tradition of percussion music and experimental instrument building. Using scientific methods in the production of acoustic sound objects gives us a deeper understanding of timbre and the artistic possibilities inherent in these objects.

We propose a method for simulating the timbre of the sound objects using models of plates and mallets. This method has been implemented in Supercollider as a source-filter model. In this model the excitation by the mallet is the source, and the transfer function of the metal plate is the filter. The model is simplified and easy to calculate, and produces good predictions of resonances and reverberation times for the plates in this project.

A sound recording was made using a number of different mallets, and dominant peaks were calculated. When measurements from the actual plates were compared to the predicted resonances, most predicted resonances were near the measured resonances.

As the only input variables are the physical properties of the plates, we expect the model to be valid also for other metals and similar materials. This makes this model an easy to use alternative to other known methods for predicting the timbre of free hanging vibrating plates.

## 7. ACKNOWLEDGMENTS

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