# RESONANT BODIES:
# CALIBRATION TOOLS FOR SONIC ARCHITECTURES

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*'Resonant Bodies' - Emma-Kate Matthews 2021/22*

## [RESONANCE IS...]

*/ˈrɛz(ə)nəns/*
*The word 'resonance' originates from the Latin resonare:*
*re (as in 'again' or 'back') sonare (a verb meaning 'to sound', related to*
*'sonus' meaning 'sound')*[1] .

*In language:* **Resonance is** a word often used to discuss a sympathetic condition, where either a mechanical vibration or an emotional sentiment is shared between two or more agents. Throughout the twentieth century, the word has become common as 'a musical figure of speech'[2] in situations where things are 'in-sync' or, for instance, when a memory, an idea or a thought is 'echoed'[3] or understood between multiple parties.

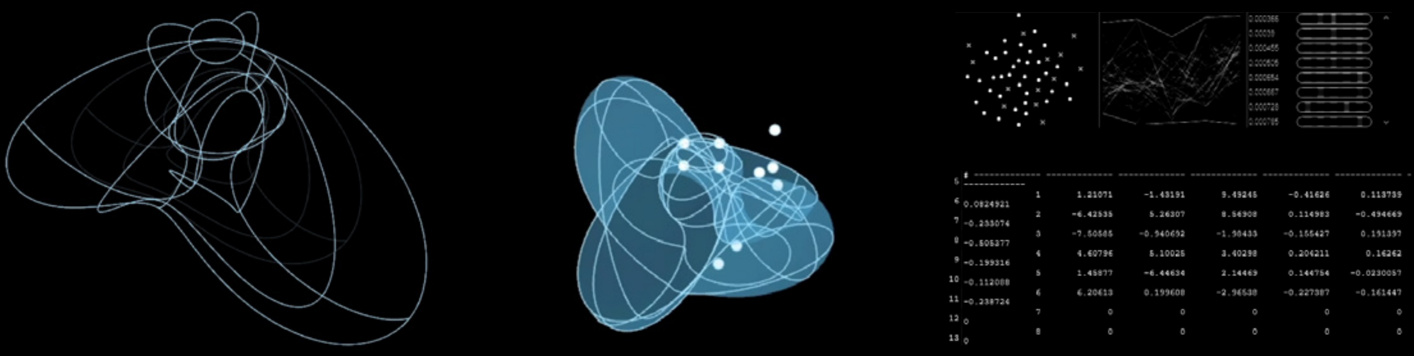
*In the discipline of musical acoustics:* **Resonance is** the phenomenon by which instruments become audible. All physical things have one or more resonant frequencies at which they will naturally vibrate. Vibrations within the strings, skins and surfaces of a musical instrument are amplified when the frequency of an excitation source matches the natural resonant frequency of the body that is being vibrated. These bodies are usually excitable in response to multiple resonant frequencies which often have a harmonic relationship to each other. The most sonically present of these vibrations is referred to as the fundamental tone. Other tones which are present, but quieter are called overtones or harmonics, or if the frequency doesn't have a whole-number relationship to the fundamental, it is known as a partial. The presence of harmonics and partials is what characterises the timbre or sonic character of an instrument. A melodic instrument such as an Oboe, typically has very clearly defined harmonics resulting in a clear-sounding tone where the fundamental pitch can very easily be identified. By contrast the harmonicity of the partials in Timpani — an instrument which performs both a melodic and a percussive role — is much less defined, but (if well-tuned) it is still possible to discern a fundamental pitch, despite the overall sound appearing less tonally pure.

*In the disciplines of architecture and structural engineering:* **Resonance is** often considered problematic as it is capable of destroying structures or making them uncomfortable to inhabit. One of the most recent and high-profile examples of resonance-induced discomfort is captured in the accounts of the horizontal swaying of London's Millennium Bridge (since named the 'wobbly bridge'), prior to the installation of passive dampers. The synchronicity of the dynamic loads of walking pedestrians coincided with the natural resonant frequency of the bridge causing excessive oscillations, to the point where 'pedestrians had to hold onto the balustrades, or stop walking to retain their balance.'[4] Just short of 200 years prior, the same phenomenon led to the destruction of Manchester's Broughton Suspension Bridge: A group of soldiers, marching at the regulation rate of 76cm per minute, enjoyed the synchronicity between their step and the rhythmic sway of the bridge so much that they changed their pace to fall 'in-sync' with its movements, until it collapsed.[5] Albert Bridge in London (completed in 1873) was one of the first bridges to display a sign, following this disaster, warning marching groups to "break step" which is still visible today.[6] In the interest of avoiding future resonant disasters, it is now possible to digitally calculate and simulate the resonant frequencies of proposed three dimensional structures using modal analysis: 'Modal analysis is the process of determining the inherent dynamic characteristics of a system in forms of natural frequencies... and using them to formulate a mathematical model for its dynamic behaviour.[7]' Autodesk Fusion 360 is a widely-used digital tool which offers multiple methods of modal frequency analysis, for constrained and un-constrained bodies. The modal frequency simulation is a function of the geometry, mass, and stiffness of the structure, as well as any conditions for its constraint and applied tensile or compressive loads.[8]

*In between disciplines:* **Resonance is** productive when established between acts of practice and research; skills and experience; explicit and tacit knowledge; sonic and spatial disciplinary norms; and so on... This type of resonance can be compared to Tim Ingold's notion of "togethering", as examined in his 2017 publication on the topic of "Correspondences".[9] The concept of togethering provides a useful theoretical framework for understanding the difference between projects where collaborators share interactions but keep within the typical extents of their disciplinary fields, and those where ideas, skills, knowledge and tools are openly shared and in constant correspondence. Ingold makes a precise distinction between the concepts of correspondence and interaction: 'If interaction is about othering, then correspondence is about togethering'.[10] This is a particularly important distinction to acknowledge in the context of any work seeking to establish a mode of practice which truly encompasses multiple disciplines: Work in which knowledge is not ring-fenced and disconnected from its neighbours (as is becoming increasingly typical between architectural, musical and acoustic fields). At this point, it is also important to establish some clarity about the differences between multi, inter and trans disciplinary modes of practice: To paraphrase theoretical physicist Basarab Nicolescu, disciplinary fragmentation occurs when 'each discipline... [becomes] more and more specific'[11] and that, recent technological developments are partly responsible for this situation as the modern world manifests an increased complexity of communication and thought, in contrast to the 'simple, one-dimensional reality of classical thought'.[12] Though this complexity is advantageous to the development of each discipline in question, it also makes it harder to establish the togetherness that inter and transdisciplinary practice both appear to offer. According to Nicolescu, 'Multidisciplinarity concerns studying a research topic not in just one discipline, but in several at the same time'[13] which on the one hand creates the potential for conversations and overlaps across domains, but ultimately results in a situation where each discipline maintains a highly individual and self-contained body of knowledge. Interdisciplinarity goes one step further towards togethering, by offering 'the transfer of methods from one discipline to another'.[14] Interdisciplinary also offers opportunities for the cross-pollination of ideas and methodologies, but still remains 'within the framework of disciplinary research'.[15] Transdisciplinarity is perhaps the closest to Ingold's notion of togethering as — according to Nicolescu, and as the title suggests — it transcends disciplinary boundaries, enabling knowledge to be created and shared between, across 'and beyond all discipline'.[16] Each of these three structures for practice have their own advantages, however it seems that transdisciplinarity is closer to the notion of togethering than the other modes. The self-coined term "spatiosonic" can be used to describe collaborative resonances between sonic and spatial disciplines where many pre-existing boundaries between involved parties become blurred due to a generous sharing and overlapping of skills, knowledge, techniques, and tools. A collaborative environment in which many of the pre-existing boundaries between disciplines are blurred due to a generous sharing and overlapping of skills, knowledge, techniques, and tools.

*In establishing spatiosonic[17] practice:* **Resonance is** then a symbiotic[18] state between the multiple agents of site and sound, listener and performer, designer and composer, air and material matter, acoustics and musical desires, instruments and the tools that make them, and so on. The concept of resonance in this context discusses more than just the reinforcement of vibrations as a mechanical phenomenon, the work also discovers and articulates physical and conceptual compatibilities of the experiences, knowledge and ideas that are shared between the site, the listener, the performer, the composer, and the designer. The concept of resonance represents a state in which all these entities are togethering not only in transdisciplinary resonance, but as part of a wider spatiosonic ecology.

*In the Resonant Bodies project:* **Resonance is** established by means of a collection of instruments which are each designed and manufactured to initiate resonance, both mechanically (producing tone) and culturally (producing conversation and a desire for collective understanding).



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5 # ----------- ----------- ----------- ----------- ----------- ----------- -
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                 1     1.21071    -1.43191     9.49245    -0.41626     0.113739
6 0.0824921
                 2    -6.42535     5.26307     8.56908     0.114983   -0.494669
7 -0.233074
                 3    -7.50585    -0.940692   -1.98433    -0.155427    0.191397
8 -0.505377
                 4     4.60796     5.10025     3.40298     0.204211    0.16262
9 -0.199316
                 5     1.45877    -6.44634     2.14469     0.144754   -0.0230057
10 -0.112088
                 6     6.20613     0.199608   -2.96538    -0.227387   -0.161447
11 -0.238724
                 7           0           0           0           0           0
12 0
                 8           0           0           0           0           0
13 0
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*Modal Frequency Analysis in Grasshopper - Emma-Kate Matthews 2021/22*

'Resonant Bodies' at Shoreham by Sea for Brighton Festival - Emma-Kate Matthews 2021/22

When struck, the instruments physically resonate, sounding multiple tones simultaneously and stimulating musical composition and performance. Their uncanny appearances — resembling tuning forks, or bells — also arouse curiosity in those who come across them for the first time, sparking conversation with collaborators, audiences and strangers who share a desire to understand what they do and how they sound. From design through manufacture, composition, performance and listening, the instruments find resonances between the multifarious musical and architectural tools, methodologies and theories that are responsible for these stages of their becoming:

*In a design context:* **Resonance is** defined as a series of sonic desires, which originate in the ongoing development of new projects and lessons learned from previous projects. For the resonant bodies, the important sonic criteria began as follows:

- To be polyphonic, sounding at least one audible interval of a minor second (or close)
- To have a rich timbral quality which has tonal clarity, but is not 'pure'
- To sound as low as possible
- To ring for as long as possible

These criteria must also be balanced with several practicalities of fabrication, the most important of which is to fit within a bounding box of 88 x 88 x 125mm due to a manufacturing constraint.[19]

The musical interval of a minor 2nd is particularly important in many of the compositions in this research, as the closeness of the tones (even at very low frequencies) creates a beat pattern, or an oscillation in the volume level which is created by alternating moments of constructive and destructive interference when the two similar tones sound simultaneously. This interval is used as a rhythmic device, in relation to ideas of states of motion or constant change. This temporal instability occurs when a played rhythm is overlaid with the beat pattern. The resonant bodies are designed to resonate at multiple frequencies when struck, meaning they are polyphonic and capable of achieving such tonal interference.

The earlier generation of resonant bodies are tuning fork-like as they have twin prongs. This geometry can be tuned to sound a reasonably pure tone when struck, as this particular shape concentrates most of the vibrational energy around the fundamental mode (or the first harmonic). The instruments differ from regular tuning forks in that they have more than one set of prongs, allowing for multiple fundamental tones to sound simultaneously. The geometry which joins them is also designed to transfer vibrations to another body, such as a table, a sound board, or the bony process at the back of an ear.[20] In order to listen to the fork-like bodies, it is necessary to make direct contact with, or to at least be in very close proximity to them, either as the body of the listener, or through another resonant body, such as a contact microphone. The later generation of resonant bodies are more bell-like as they are larger, they resonate for longer and their geometry is such that there is more than one audible mode of vibration, making for a much more complex tonal profile and the ability to achieve polyphony within a more straightforward organisation of resonating pieces.

Both generations of instruments are designed through a combination of intuitive and calculative design methods. Learning from other fork and bell-like constructions and the playable inventions of instrument-maker Harry Partch,[21] it has been possible to make a series of empirically informed decisions as to where to begin when defining the geometry and materiality of the resonant bodies. The initial designs are first defined in 3D modelling software Rhino as 3D meshes. Their vibrational performance is then simulated using modal frequency analysis software[22] as is typically used for simulating resonance in bridges, buildings and other large-scale architectural structures. The design process for the fork-like bodies is arguably more straightforward than for the bell-like ones[23] as a very simple formula already exists for calculating the tone that a tuning fork will produce, with variables relating to its dimensions and materiality.[24] For the forks, the modal frequency simulation is simply used as a double-checking method following a calculation of their predicted tonal properties using the formula, and prior to their (costly and time-consuming) manufacture. For the bells, the role of the simulation was much more important as their geometry results in more complex vibrational behaviours, meaning that their predicted tonal qualities are much more difficult to ascertain from formulas alone. In this case, the simulation allows for a more computationally efficient design process, utilising the evolutionary solvers in 3D parametric plugin Grasshopper[25] to do the hard work of iterating through different options before settling on a geometry that is optimised enough to produce the desired tonal result.

The custom Grasshopper definition outputs both a visualisation of vibrational characteristics (most importantly, the intensity of modal displacement) and the auralisation of resultant tones. The aforementioned modal frequency simulation tool in Autodesk Fusion doesn't offer auralisation as this particular software is more commonly used for calculating vibration in structures where the sound they make is not important. However, the ideas which govern the logic of the geometry, the quality of the sound it produces and the structure of the music in which the sound features, were all developed in tandem meaning that sonic feedback was as equally important as visual feedback, at every stage of the design and composition process. The flexibility of Grasshopper's parametric interface, and the ability to directly edit the code that defines each component, made it possible to customise and appropriate an existing frequency analysis tool[26] in order that small-scale structures could be analysed, visualised, auralised and optimised parametrically and iteratively.

The flexibility of the parametric system also made it possible to quickly test design features that were otherwise largely based on experience and instinct, such as the inclusion of claws around the rim of the bells. These claw-like protrusions are based on the 'tines' which give Indian elephant bells their distinctive sound and appearance. The literature on the design of elephant bells is extremely limited, however it is understood that the addition of tines produces lower frequency vibrations, even when the overall dimensions of the bell are relatively small. To quote a specialist paper titled 'Some Experiments on an Elephant Bell':

> *'the designer of this bell sought to achieve a low and mellow tone quality in a small-sized unit. The prongs extending downward from the sound bow have the physical effect of greatly increasing the effective mass at the rim of the bell without also increasing the stiffness of the shell. A substantial lowering in the vibration periods of the shell is thereby achieved'* [27]

This satisfies two of the aforementioned design criteria. The frequency beating due to the sounding of close tones is then achieved by introducing asymmetry in the geometry. In bell design, this phenomenon is referred to as a 'doublet' and gives the bell a rich timbral quality (another design criterion): '...strong beats [are] due to the irregular mass distribution of the shell.[28]'

A combination of multiple disciplinary approaches, ranging from the results of personal observation to precise calculation, gives rise to a much greater scope for speculation and invention in the design of new instruments. Resonant Bodies exemplifies an approach in which architectural tools and methods are employed to design and make these instruments, the sounds of which are then used to articulate spatialised compositions, or spatiosonic constructs.

*'Resonant Bodies' Eccentric Version - Emma-Kate Matthews 2022*

# [Endnotes]

1 Oxford English Dictionary, Resonate. Accessed June 24, 2022 https://www.oed.com/view/Entry/163743

2 Zimmer, Ben. 2010. Resonate, The New York Times, November 18, 2010. Accessed June 24, 2022. https://www.nytimes.com/2010/11/21/magazine/21FOB-onlanguage-t.html

3 The word ‘Echo’ is used as another acoustic metaphor to discuss things with shared characteristics.

4 Dallard Pat, Fitzpatrick Tony, Flint Anthony, Low Angus, Smith Roger Ridsdill, Willford Michael, and Roche Mark. 2001. London Millennium Bridge: Pedestrian-Induced Lateral Vibration, Journal of Bridge Engineering 6 (6): 412–17.

5 Woolfson, Michael Mark. 2014. Resonance: Applications In Physical Science. Icp. P21

6 The Tacoma bridge (otherwise known as Galloping Gertie) is another famous example, which was originally thought to have collapsed due to mechanical resonance alone, however engineers have since discovered that “aeroelastic flutter” caused by the wind was possibly the main contributor to its dramatic collapse. Ibid. P22

7 Fu, Zhi-Fang, and Jimin He. 2001. Modal Analysis. Elsevier.

8 Autodesk, Modal frequencies study, accessed July 13, 2022 https://help.autodesk.com/view/fusion360/ENU/?guid=SIM-MOD-FREQ-ANALYSIS

9 Ingold, Tim. 2017. Knowing From the Inside: Correspondences. The University of Aberdeen.

10 Ibid. P41

11 Nicolescu, Basarab. 2002. Manifesto of Transdisciplinarity. SUNY Press. P34

12 Ibid, P34

13 Ibid, P42

14 Ibid, P43

15 Ibid, P43

16 Ibid, P44

17 “Spatiosonic” is a self-coined word that the author uses to describe correspondences between spatial and sonic concepts and/or behaviours.

18 The word “symbiotic” from the Greek sumbiōsis ‘means a living together’, from sumbioun ‘live together’, from sumbios ‘companion’. This word is resonant with Ingold’s notion of “togethering”

19 These dimensions are dictated by the manufacturer’s available mould sizes. Of course, much larger sized bells are possible at a different foundry, however a project of this scale would need a much larger budget which may be possible for future iterations.

20 This bony part just behind the ear is called the mastoid process and conducts sound to the inner ear when subjected to vibration from devices such as tuning forks or bone conducting hearing aids.

21 In particular his ‘Cloud Chamber’, which is a series of suspended bell-like bowls, made from glass carboy bottles

22 Autodesk Fusion was initially used; however I then discovered the parametric plugin for Grasshopper called Alpaca 4d, developed by engineer M. Pellegrino

23 For simplicity, the fork-like and bell-like bodies will simply be referred to as ‘forks’ and ‘bells’ from here onwards

24 Tikhonov, A. N., and A. A. Samarskii. 2013. Equations of Mathematical Physics. Courier Corporation. Pp152 - 155

25 ‘Grasshopper is a cutting-edge parametric modelling tool which works with Rhino to allow a powerful and efficient new way of designing... Via a visual programming interface that runs inside Rhino, Grasshopper allows the dragging and placement of components onto a canvas’, Accessed July 4, 2022. https://simplyrhino.co.uk/3d-modelling-software/grasshopper

26 With the help of engineer and software developer M. Pellegrino

27 Brailsford, H. D. 1944. Some Experiments on an Elephant Bell. The Journal of the Acoustical Society of America 15 (3): 180–87. P187

28 Ibid.