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"Frozen Music:" The Synthesis of Music and Mechanical Theory in Vitruvius' De Architectura

Goethe once observed: "I call architecture frozen music . . .; the influence that flows upon us from architecture is like that from music." Goethe's analogy between architecture and music likely had a specific reference to the Classical architectural structures he encountered on his Italian tour, but metaphorical linkages between architectural and musical descriptions have an ancient genesis. This paper addresses the ways that the overlap of music and architecture were reflected in the philosophy and practice of the Roman Imperial architect, Vitruvius, whose writings on architecture and mechanics in De Architectura were profoundly influenced by musical theories. The Vitruvian view was that structures and mechanical objects such as war machines and musical instruments should be designed to conform to the ratios and proportions that constitute the natural world. The place to find those proportions identified was in Greek musical theory, which described the motion of the planets as comprising, in effect, a machine to make music.

In the first book of *De Architectura*, Vitruvius writes about the importance for an architect of being well-versed in a variety of disciplines, but especially music, explaining that: "the architect should know music [*musicien*] in order to have a grasp of canonical and mathematical relations." That way architects "will be most easily capable of using the principles of Nature to design theaters that enhance the voice for the pleasure of the audience." Elsewhere in *De Architectura*, under the influence of the Greek music theorists Aristoxenus and Pythagoras, Vitruvius explores how columns in temples should be placed at the same intervals that produce tonal patterns on strings, how stone theaters can be made to echo like musical instruments, and how a catapult should be tuned like a lute.

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I will talk briefly about the connections between music theory, architecture, and mechanics that Vitruvius identifies in *De Architectura*. I will begin by examining his terminology, which is shared not only between architecture and music, but also with rhetoric. I will then look at how he applies what we think of today as musical theory to building and theater design. Finally, I will turn to his discussion of mechanical design, exploring how historical definitions of mechanics [*mechanice* and *machinatio*] and views of the relationship between the natural world and musical harmonies influenced his theories about harmonious architectural design, as applied to mechanical devices for war and entertainment.

Vitruvius is explicit about the Greek antecedents for the Latin terms in his discussion of design, which appears at the beginning of Book I:

> Architecture consists of ordering [*ordinatione*], which in Greek is called *taxis*, and of design [*dispositione*] – the Greeks call this *diathesis* – and shapeliness [*eurythmia*] and symmetry [*symmetria*] and correctness [*decor*] and allocation [*distributione*] which is called *oikonomia* in Greek.

Many of these terms, found by Vitruvius in the writings of Aristoxenus, one of the earliest Greek musical theorists, also appear in Cicero's *De Oratore* and other sources about the science of oratory and language. *Taxeis*, Aristoxenus explains in *Elementa Harmonica*, indicates the various possible organizations and orderings of rhythmic durations; *symmetriai* is used to illustrate the various proportional relationships of different rhythmic and durational lengths to one another; *eurythmia* describes a beautifully constructed rhythmic structure. As Cicero and Vitruvius use them, these terms have much the same meaning in rhetoric and architecture.

The link between rhetoric and architecture evident in *De Architectura*, goes beyond the borrowing of terminology by an architect. It is particularly striking in the conception of *memoria* [memory], which was regarded as one of the most important elements of oratory. In rhetoric, the speaker is urged to recollect elements of a speech by imagining walking through

an architectural space in which the ideas are placed like statues in architectural niches. Vitruvius similarly describes the purpose of memorial statues ornamenting real architectural spaces. For example, he writes that Caryatids were built into buildings in order that "the notorious punishment of the Caryate women would be recalled to future generations." He also writes that the hut of Romulus on the Capitol serves to commemorate the foundations of Rome: "The house of Romulus shows us — and calls to mind — the ancient ways." Furthermore, in Vitruvius's time, the fashioning of Augustus's new public buildings served to memorialize the Emperor's accomplishments for the Roman public, much like the crafting of a persuasive speech delivered before the *civitas*.

Vitruvius uses the Greek term *musicen*, rather than the Latin *musica*, in Book I of his treatise to indicate that he is thinking of Greek music theoretical tradition, rather than the practice of musical performance in Rome. It is the mathematical basis of Aristoxenean theory that helps produce an architecture that is closer to nature, and thus more beautiful and useful. Vitruvius refers directly to his Greek source, pointing to a diagram of notes, scales and intervals that Aristoxenus devised. He explains: "Anyone who truly pays attention to his reasoning will be most easily capable of using the principles of nature to design theaters that enhance the voice for the pleasure of the audience." Just as composers organize and divide tones in temporal "space" to create music, architectural designs of temples and theaters consist of a proportioning of volume and physical space to enhance visual and auditory experiences.

Vitruvius's discussion of proportions also derive ultimately from the Greek music theoretician Pythagoras. *De Architectura* is filled with allusions to Pythagorean numerical systems, including the famous proof of the Pythagorean Theorem ($a^2 + b^2 = c^2$). Using musical instrument string length ratios, Pythagoras determined the basic intervals of an

octave (2:1), fifth (3:2), and fourth (4:3). Pythagoras's ideas about music theory had

architectural applications, but they also had mystical significance for Pythagoras and his

followers, who believed that these were the ratios underlying the construction of the entire

cosmos.

Vitruvius applies music theory throughout his descriptions of temple and theater

design. In Book II of *De Architectura*, he shows how columns should be spaced in temples

according to the same intervals as tones in music. He uses the term "pycnostylos" to refer

to the closest possible spacing of columns, "crebis columnis." The prefix "pyknos," the

Latinized form of the Greek πυκνος, alludes to one of the musical intervals defined by

Aristoxenus, the "πυκνον." The πυκνον is followed by a ditone, or an interval of two

tones. When added together, the total interval spanned by the enharmonic tetrachord is

equivalent to two and half tones. This corresponds exactly to Vitruvius' definition of the

spaces between the equivalent points on a column as equaling two-and-a-half column

widths. Different types of temple fronts are analogous to different types of musical scales,

each with its own aesthetic and subjective qualities. Vitruvius also uses the term *genus* (or

"families") to distinguish between different types of structures for building design. Here

too, he uses musical ideas to explain how details of buildings should, and should not, be

arranged. As he instructs:

> If Doric entablatures are sculpted with dentils in the cornices, or triglyphs show up
> atop cushion capitals and Ionic entablatures, so that characteristics from one set of
> principles have been carried over into another type of work, the appearance of the
> result will be jarring, because the work was established according to a different
> sequence of conventions.

This passage recalls Aristoxenus's classification of tetrachords into different families, called

γενοι. Vitruvius likens the architectural orders (Doric, Ionic, Corinthian) that define the

elements of a building to the different sorts of musical units (Enharmonic, Chromatic, and Diatonic) that constitute the basic structural language of the scale.

Vitruvius also uses musical principles in talking about how to design stone theaters with improved acoustics. In Book V, again borrowing from Aristoxenus, he suggests that that architects should place variously shaped bronze vessels, or *echea*, at specific vertical and horizontal levels. Each, by virtue of what modern physicists call Helmholtz's law, will resonate by sympathetic vibration at a specific pitch of the musical scale – just like a Coke bottle when you blow over its top. He thus conflates the design of musical performance space and the musical instrument, and by extension shows as analogous the tasks of the architect and the instrument designer, who in ancient times was often the musician himself. For Vitruvius, the edifice of a theater should be perceived to resonate like a musical instrument.

In Book X Vitruvius employs music theory to describe the design of the machines for which, as an imperial architect, he was responsible. For example, when discussing the design of war machines, such as catapults, he uses Pythagorean music formulas to help describe how these devices should be structured, and he expressly compares the catapults to stringed instruments. He explains that: "the architect should know music in order to have a grasp of canonical and mathematical relations, and besides that, to calibrate [*temperaturas . . . recte facere*] ballistae, catapults, and scorpiones." In fact, a string player would use much the same process that Vitruvius describes for calibrating catapults in order to tune a harp, cithara, or lyre - or that a violinist tuning up for a concert today would use: by comparing the pitch of one vibrating string to another, and adjusting the tuning pins until the desired interval is reached. He writes: "In this way catapults are adjusted to tone [*ad sonitum*] . . . according to the musical sense of hearing [*musicis auditionibus . . . temperantur*]." The

connection between tuning musical instruments and war devices seems to have been common. Thus, a passage in Ovid's *Metamorphoses*, written around the same time as *De Architectura*, uses the verb *tempero*, which is the word Vitruvius also uses, to describe stringing and tuning both a cithara and a bow and arrow: as Ovid writes about the cypress tree, "once a boy, but now a tree: loved by the god who tunes the lyre, and strings the bow [*qui citharam nervis et nervis temperat arcam*]." Other vocabulary in the Vitruvian discussion of war machines also recalls musical practice. The word *foramina* describe the spring holes in the headpiece of the war machines. The same word is often used to describe the stops in a musical pipe, or the apertures of a musical flute, which are manipulated by the musician to control the pitch of the instrument. Finally, Vitruvius uses the word *nervus* to describe the sinew cords that must be "tuned" so the device will shoot forward a straight shot; *nervus* is also the word for a musical string on an instrument. Pythagoras believed that the string length ratios he determined for the basic intervals of an octave (2:1), fifth (3:2), and fourth (4:3) had external architectural applications because they were the ratios that underlay the construction of the entire cosmos. This reasoning justifies for Vitruvius the use of music theory as a measuring principle for good mechanical design.

Vitruvius's mechanical designs were not exclusively for practical devices, whether martial or for civic improvements. At the end of his treatise, in Chapter 8 of Book X, he turns to actual instrument-building, detailing how to construct a *hydraulis*, or water organ, based on the description Ctesibus, a Greek engineer from the third-century B.C.E. and, again, following principles of Greek music theory. Used for entertainment in theaters and at gladiatorial games, the *hydraulis* was widely admired; Cicero likened its sound to the beauty of flowers. The organ consisted of three main elements: a row of pipes (also called a *syrinx* or pan flute); a mechanism for compressing the air and delivering it to the pipes; and a system

by which the organist can control how much wind goes into which pipe. The pipes of the *hydraulis* are tuned in groups of tetrachords, hexachords, and octochords, classifications that are necessary according to the precepts of Aristoxenus. Vitruvius presents the *hydraulis* as a proof of what can be achieved under the guidance of Aristoxenus, and of the effectiveness of Pythagorean mathematical calculations in structuring both machines made by architects and sounds played by a musician.

Echoing Pythagoras, Vitruvius proposes that *Machinatio* requires the emulation of nature and physics in order to develop mechanisms that make life easier and more pleasant. "Every mechanism has been created by nature," he explains, and the most important natural phenomenon that governs *machinatio* is the rotation of the sun, moon and stars. He adds:

> Therefore when our forebears had observed that this is how things are, they took examples from nature and imitating them, spurred by these divine exemplars, they achieved the development of life's conveniences.

Machinatio is, then, the art of devising architectural elements that exploit natural phenomena and physics, and the rotation of celestial bodies is the phenomenon that serves as the primary source in the design of *machinatio*. As Vitruvius also knew, Pythagoras believed that the rotation of the celestial bodies themselves is governed by music. Thus, the motion of orbiting planetary bodies, which Vitruvius posits as the main source of *machinatio*, is in turn commanded by *musicen*, or music theory. The natural world is a great machine, one that makes music, and in that respect it is both the source for all architectural design principles, and the proof of their effectiveness. Thus, Vitruvius concludes his text with an extensive description of the most musical of all architectural projects – mechanics – once again affirming the primacy of musical theory and philosophy in *De Architectura* and revealing the insightfulness and truth of Goethe's notion that Classical structures can be interpreted as "frozen music."