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Frozen Music: Music and Architecture in Vitruvius' *De Architectura*

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Abstract

This paper explores the convergence of musical and architectural theory in Vitruvius' *De Architectura.* Section 1 describes Vitruvius' architectural lexicon, borrowed from Aristoxenus (I.2), and explores his description of the laws of harmony, modeled on *Elementa Harmonica* (V.4). Section 2 explores how Vitruvius proposes using music theory in practical architectural design, including construction of columns using architectural orders analogous to Aristoxenian *genera* (I.2.6; IV.1); acoustical designs for theatres (V.5); and the development of machines, including siege engines 'tuned' like musical instruments (X.12) and water-organs [*hydrauli*] constructed to execute all the different varieties of tuning (X.8). Section 3 reflects on Vitruvius' use of analogies with a musical instrument, the *sambuca*, to explain his understanding of cosmic harmony and architectural form, and his possible sources (VI.1). Finally, Section 4 discusses Vitruvius' ideas about the importance of a liberal arts education that includes study of music theory. The best architects, Vitruvius explains, can discover in music the secrets to forms they both encounter in nature and create themselves.

Keywords

Vitruvius – Aristoxenus – architecture – mechanical design – *echea* – *sambuca* – liberal arts education – *encyclios disciplina*

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The German philosopher Friedrich Wilhelm Joseph von Schelling reflected that 'architecture, in general, is frozen music [*erstarrte Musik*] . . . it is a concrete music'.[1] Schelling proposed that this metaphorical linkage between music and architecture had an ancient genesis, referring specifically to the Roman Imperial architect Vitruvius, who used harmonic proportions in his architectural designs.[2] Indeed, Vitruvius' ten-volume treatise *De Architectura*, covering the fields of architecture, gnomonics, and mechanics [*aedificatio, gnomonice, machinatio*], was profoundly influenced by earlier Greek musical theorists. Under the guidance of Aristoxenus, Pythagoras, and other predecessors whom he calls his *maiores*,[3] Vitruvius explores how columns in temples should be designed by analogy with the various musical genera, how stone theatres can be made to resonate like musical instruments, and how the cords of a catapult should be tuned to a precise musical pitch.

This article addresses the ways Vitruvius applied and appropriated Greek music-theoretical principles. I begin by examining how Vitruvian architectural vocabulary and syntax correlates to specific passages in Aristoxenus' music-theoretical works, *Elementa Harmonica* and *Elementa Rhythmica*, as well as to various elements of the Pythagorean musical theoretical tradition. I then explore the role music plays in the design of the architectural orders, theatres, and machines. I next discuss a curious musical analogy in VI.1 likening the structure of the cosmos to a *sambuca* (in Greek, *sambykê*), a type of arched harp, and that image's possible antecedents. Finally, I examine Vitruvius' emphasis on the importance of the *encyclios disciplina*, the 'rounded education' in the liberal arts, in the making of the ideal architect. This system of study introduces the aspiring architect to a wide variety of disciplines, including music, as a key to understanding the basic principles of man-made architectural forms—and, indeed, the natural architecture of the cosmos itself.

I Vocabulary, Syntax, and Rhetorical Argument

The terminology of music theory plays an important role in *De Architectura* from its earliest chapters. After a brief introduction that pays homage to his

1 Schelling 1907, 241. The idea was echoed in Goethe's remark of March 23, 1829, invoking the same analogy to observe that "the mood that arises from architecture comes close to the effects of music." Cf. Eckermann 1986, 340.

2 Schelling 1907, 241.

3 Vitr. X.1.4. Subsequent references to *De Architectura* omit Vitruvius' name. All English translations from Latin and Greek are based on, but not always identical to: Rowland 1999, Barker 1989, Hett 1963, and Pearson 1990.

patron, Caesar Augustus, Vitruvius explains his goal of setting forth the philosophies and theories [*rationes*] of architecture[4] and enumerates the disciplines in which the architectural practitioner should be trained. Music theory is of central importance:

> The architect should know music [*musicen*] in order to have a grasp of harmonic and mathematical relations [*uti canonicam rationem et mathematicam notam habeat*],[5] and besides that, to calibrate *ballistae*, catapults, and [the small catapults called] *scorpiones*. . . . In theatres, likewise, the bronze vessels—the ones Greeks call *echea*—which are enclosed underneath the seats, are placed according to mathematical principle based on their pitch. . . . As another example, no one could possibly create water organs [*hydraulicas*] and other similar devices without recourse to musical principles [*musicis rationibus*].[6]

He immediately focuses on the practical importance of ancient Greek music theory for architectural and mechanical design. Here Vitruvius uses *musicen*, the accusative of the Latinised version of the Greek term *mousikê*, rather than the Latin *musica*, indicating that he is thinking of the Greek theoretical tradition rather than contemporary Roman musical practices and philosophies. Vitruvius proposes that design, spatiality, and proportional measurement can only be fully understood if the architect receives a proper musical training in *canonicam rationem et mathematicam*. Each of the practical applications Vitruvius suggests will receive a more thorough explanation later in his treatise, but from the outset, he takes care to emphasise that these applications all have 'recourse' to the *rationes* of musical theory.

Because the term *canonica* appears here in juxtaposition with *mathematica*, it seems to refer to the study of the divisions of the musical *kanôn*, or monochord, which was often associated with the Pythagorean school.[7] Saliou 2009, however, suggests that Vitruvius may have understood *canonica* more in the sense in which it concerned the *mousikoi*, perhaps referring to "une approche

4 I.Praef.3.

5 I follow Fleury 2003 and Saliou 2009 in translating *canonicam* as 'harmonic'. See Saliou 2009, 179-181, who notes that "aux yeux de Vitruve, l'étude des intervalles musicaux et celle des proportions mathématiques se confondent" (180).

6 I.1.8-9.

7 Saliou 2009, 180. Creese 2010 points out that the monochord did not actually date back to Pythagoras, although many imagined it did; the monochord does not appear in any references before the late fourth century BC.

globale et sensible de la musique" rather than to a more purely theoretical study of Pythagorean musical ratios.[8] Either way, Vitruvius' point is that a knowledge of music is key to understanding the systems which produce architecture and machinery that is closer to nature, and thus more beautiful, convenient, and useful.

In I.2.1, Vitruvius introduces the basic architectural vocabulary that he will use throughout the ten books:

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

Vitruvius has not invented these key terms; once again, he borrows from both Pythagoras and Aristoxenus. Five out of six of the terms are Greek, indicating that he has taken them from earlier Greek sources; Latin translations of these terms appear often in Roman philosophical discourses from other disciplines, such as rhetoric.[9] They also appear in music theory—and here the correspondence seems strongest. *Taxis*, *eurythmia, symmetria*, and *diathesis* all play an important role in Aristoxenus' *Elementa Rhythmica*, where they are defined in a very similar manner. In *Elementa Rhythmica* II.8, Aristoxenus uses the first three terms when discussing the principle of duration, the division of which constitutes rhythm:

> For many of their proportions [*symmetriai*/συμμετρίαι] and organizations [*taxeis*/ τάξεις] are experienced as alien to perception, few as conformable to it and capable of being organized into the nature of rhythm. The *rhythmizomenon* is in a way common to both unrhythmicness and rhythm: for the *rhythmizomenon* is by nature capable of receiving both kinds of structure, the rhythmic [*eurythmon*/εὔρυθμον] and the arrhythmic.[10]

Diathesis appears earlier in *Elementa Rhythmica* II.5, when Aristoxenus compares the way in which a duration is divided into different rhythmic groupings

8 See Saliou 2009, 181.

9 See Brown 1963.

10 Aristox. *El. Rhyth.* II.8. The term *rhythmizomenonon* indicates a collection of sounds or impulses that can be arranged in ways that are either rhythmic or arrhythmic; see Pearson 1990, 52-3.

to how a speech is divided into different words. He speaks in abstract terms about how any object is divided into component parts: 'No object capable of assuming different shapes is to be identified with any of the shapes. The shape is a particular arrangement [διάθεσις] of the parts of the object'.[11] These four terms are all located closely together in the text of *Elementa Rhythmica*, making it easy to imagine that Vitruvius appropriated the fundamental vocabulary of musical rhythm for his architectural lexicon from this one source.[12]

For Aristoxenus, *taxeis* indicates the various possible organizations and orderings of rhythmic durations; *symmetria* illustrates the various proportional combinations of different rhythmic and durational lengths; *eurythmia* describes an artistically well-constructed rhythmic structure;[13] *diathesis* describes the various arrangements in which the components of a whole can be arranged. As Vitruvius uses them, *taxeis* indicates the various arrangements of individual architectural components according to overall proportional schemes; *symmetria* is the correspondence of well-proportioned individual modules to each other and to the whole; *eurythmia* is the elegant composition of well-proportioned parts; *diathesis* describes the different ways individual components can be arranged in an elegant manner.[14] This juxtaposition brings to light the fundamental similarities between architecture and music: just as composers organize and divide rhythmic impulses in temporal 'space' to create music, architecture consists of a similar portioning of volume and physical space.

Two of these terms, *symmetria* and *eurythmia*, can also be understood in relation to the Pythagorean concept of cosmic harmony. Vitruvius proposes that for a structure to have *symmetria*, the measurements of its parts should relate proportionally in a manner analogous to the way parts of an organic whole relate in Nature.[15] As Jones 2000 explains, *symmetria* "reflected a cosmic

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11 Aristox, *El. Rhyth.* II.5.

12 Οἰκονομία also appears in the Aristoxenus fragments, but not, it seems, in any musical context. See Werhli fr. 31: in Iambl. *v. Pythag.* 233, the term simply connotes 'home economy'. But it is important to note that the extant fragments of *El. Rhyth.* comprise only a tiny fraction of the second book—perhaps it could have been found in the original?

13 εὔρυθμος appears four times in *El. Rhyth.* (II.7, II.8, II.24) and seven times in his complete *corpus*; cf. related terms ἔνρυθμος (II.21, II.32) and ἔρρυθμος (II.33-35). See also *Fragmenta Neapolitana* 11: 'Some *chronoi* are rhythmic [εὔρυθμοι], others quasi-rhythmic [ῥυθμοειδεῖς], others arrythmic [ἄρρυθμοι]. Rhythmic *chronoi* are those that observe the rhythmic relationship between one another accurately'.

14 See I.2.2-4.

15 Jones 2000, 41: "For Vitruvius, the task of the architect was to imitate Nature, not literally, but rather by analogy". To illustrate this point, Vitruvius famously describes in III.1.1-3 how

order that reduced ultimately to whole numbers"; these ratios of whole numbers were in turn matched by the Pythagorean ratios of musical harmonies derived from the measurements of vibrating lengths of string (1:2 = octave; 2:3 = fifth, 3:4 = fourth etc.).[16] *Eurythmia*, on the other hand, serves as a "bridge between proportion and form," merging the mathematical proportions of *symmetria* with a more subjective sense of form and grace that also allows the architect flexibility to make necessary optical or practical adjustments.[17] The terms are closely related, and Vitruvian theorists and commentators in the Renaissance often used the term *eurythmia* rather than *symmetria* to discuss how Pythagorean harmonic proportions should be applied to the dimensions of the architectural forms.[18] Although Vitruvius himself never explicitly describes any fully codified system for how to apply harmonic proportions in architecture, he does often lean towards their use in specific areas.[19] Bell 1980, Jones 2000, and Kappraff/McClain 2005, among others, have suggested that ancient Greek architects used musical proportions as the basis for temple designs, including the Parthenon and the Temple of Zeus at Akragas; notably, Vitruvius explains that he acquired his understanding of architectural *symmetria* from the studies of ancient Greek architects, many of whom had been active at that time.[20]

After defining the principal components of architecture with musically significant terms, Vitruvius devotes an extended discussion to the laws of music theory in V.4 and V.5. Here, he uses the conventional Latin term *musica*, rather

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the ratios of various measurements taken from the human body fit together, explaining that 'similarly . . . the elements of holy temples should have dimensions for each individual part that agree with the full magnitude of the work'.

16 Jones 2000, 41.

17 Jones 2000, 43. He explains that "*symmetria* . . . brings abstract beauty, but not necessarily visual beauty. This is the realm of *eurythmia*. . . ."

18 Cf. Barbaro 1556, 24, "[B]eautiful manner in music as well as in architecture is called *eurythmia*"; Barbaro 1567, 282, the architect should be "aware of *numero* . . . for those proportions which give delight to the ears in sound, applied to architectural forms, give delight to the eyes"; Barbaro 1567, 124-5, "that which is consonance to the ears is *bellezza* to the eyes". For more on the Renaissance use of harmonic proportions in architecture, with a particular emphasis on Palladio's applications, see Wittkower 1998 and Howard/Longair 1982.

19 See Jones 2000, 231 n. 47.

20 In VII.Praef.12-14, Vitruvius remarks on 'how many Greek books have been published on the subject [of *symmetria*], but very few have been written by our own people'. These works are, unfortunately, no longer extant. Rowland 1999, 267, explains that many of the texts "must have been essentially technical descriptions", but others must have expressed "broader opinions", as suggested by Vitruvius' citation of Pytheos' treatise about the Temple of Minerva (I.1.12).

than the Latinized spelling of the accusative of the Greek term *mousikê* that he had used in I.1.8 (i.e., *musicen*), but still indicates that he considers the entire field of harmonics Greek, and, specifically, Aristoxenian:

> Harmonics [*harmonia*], the literature of music, is an obscure and difficult subject, especially, of course, for those who cannot read Greek. However, if we are to explain this discipline, we must use Greek words because some of the concepts of harmonics do not have Latin names. I will therefore translate from, as clearly as I can, the writings of Aristoxenus, and I will include his diagram and his definitions of the notes, so that anyone who pays attention will be able to understand more easily.[21]

Vitruvius then offers a detailed summary of *Elementa Harmonica*, explaining the different types of vocal movement (continuous and intervallic), the three melodic *genera*, the eighteen different notes of the scale, the five tetrachords, and the six types of musical intervals. Although he takes care to translate the concepts behind these theoretical concepts into Latin, Vitruvius claims that he is unable to find exact Latin equivalents for many of the musical terms. He again implies that any Roman student who wishes to understand the various musical systems applicable to architectural practice must turn to the original Greek sources.

Although many first-century BCE Roman writers tended to rely on abridged and simplified versions of Greek textual sources composed by Latin authors, Saliou 2009 proposes that the high degree of similarity between *De Architectura* and Aristoxenus' *Elementa Harmonia* and *Elementa Rhythmica* suggests that Vitruvius was well-acquainted with the original Greek texts. Saliou notes profound structural parallels between texts of Vitruvius and Aristoxenus, indicating that Vitruvius has appropriated the same ordering of subject matter, which was *ordinatio* in ancient rhetorical terminology.[22] *Ordinatio*, of course, is also one of the six key principles described in I.2.1. It should be noted that Vitruvius does not always get his terms and definitions quite in agreement with Aristoxenus, and certain differences in tone (didactic vs. polemical) and other smaller structural differences may indicate that he was indeed using abridged manuals as his source. In either case, however, Vitruvius pays tribute

21 V.4.1.

22 Saliou 2009, XXXVIII-XXXIX. Her chart shows that Book V.4 follows the order of *El. Harm.* more closely than the other authors from the Aristoxenian tradition. See also Copeland 1995, who defines *ordinatio* as the "hierarchical arrangement of information" (206).

to his Greek intellectual *maior* by showing how the architect should follow Aristoxenus as a musical guide.

IIa Practical Applications: Architectural Orders

Vitruvius proposes a number of ways in which the musical-architectural theories he describes can be applied in everyday architectural practice. In one example, he suggests that the different architectural orders determining the types of columns used in architectural design (Doric, Ionic, Corinthian) are analogous to the musical tetrachords detailed in V.4. He uses the term *genus* in I.2.6 when discussing the rules that distinguish the orders, recalling Aristoxenus' classification of tetrachords into different *genera*:

> 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 [*genus*] of work, the appearance of the result will be jarring, because the work was established according to a different sequence of conventions.

Although the word *genus* is common in Roman literature and philosophical treatises from a wide range of disciplines, it becomes clear in IV.1 that Vitruvius may be alluding to Aristoxenus' musical *genera* when he uses terminology that closely equates the Doric order with the diatonic *genus*, the Ionic with the chromatic, and the Corinthian with the enharmonic. Vitruvius writes that the Doric column is the 'first and oldest' [*prima et antiquitus*] of the three orders, 'severe' [*severo*] and 'without decoration' [*sine ornatu*].[23] The Doric column receives its dimensions from the male human body, achieving a *symmetria* that reflects the proportions of nature.[24] Similarly, the diatonic *genus*, characterised by Aristoxenus as the 'first and oldest' [πρῶτον],[25] is described in *De Architectura* as the most 'natural' [*naturalis*] and 'simple' [*facilior*] of the

23 IV.1.3; I.2.5; IV.1.7.

24 IV.1.6: the Doric order 'obtained its proportion, its strength, and its beauty from the male body' [*virilis corporis proportionem et firmitatem et venustatem . . . coepit*]. Notably, Aristid. Quint. III.11 similarly explains that the diatonic 'displays the perceptible body, which is solid and resistant, just as the diatonic is hard and unyielding; and the constitution it has is similar'.

25 Aristox. *El. Harm.* I.19.

three *genera*.[26] The Ionic column is more slender and displays the qualities of subtlety [*subtilitas*] and grace [*gracilitas*],[27] just like the chromatic *genus* that Aristoxenus associated with the notion of sweetness[28] and which Vitruvius describes as narrow [*crebritas*], subtle [*subtilis*] and bringing delight [*delectatio*] to the listener.[29] The Corinthian column is the newest of the three, and the only order whose original creator, the sculptor Callimachus, is identified;[30] the enharmonic *genus* is also, according to Aristoxenus, the 'most sophisticated' [ἀνώτατον],[31] and according to Vitruvius is invented by human artistry and skill [*ab arte concepta*].[32] Finally, Vitruvius explains that both the musical *genera* and the architectural orders originally derive from natural models, which were shaped, refined, and applied in a variety of practical contexts by earlier ancient musicians and architects.[33] The classifications of column types found on temples and other monumental structures are thus analogous to the different Aristoxenian arrangements of a musical melody, each with its own particular and traditional aesthetic qualities.[34]

IIb Practical Applications: Theatres

Vitruvius writes that the principles of *harmonia* can also be used to design stone theatres with improved acoustics, and suggests that architects should place variously shaped hollow bronze vessels, *echea*, at specific vertical and

26 V.4.3.

27 IV.1.7-8.

28 See Aristox. *El Harm.* 1.23; also Barker 1989, 142 n. 91.

29 V.4.3.

30 IV.1.10.

31 Aristox. *El. Harm.* I.19. Barker 1989, 139 n. 73 explains that one manuscript, followed by Westphal, reads νεώτατον, or 'most recent', instead of ἀνώτατον; this alternate reading corresponds perhaps even better with Vitruvius' characterizations of both the enharmonic *genus* and the Corinthian column.

32 V.4.3.

33 Cf. IV.2.6; V.4.4.

34 Early modern Italian theorists extended this connection between the musical genera and the architectural orders still further. Thus, Barbaro 1567 explains that the diatonic *genus* is *severo* (229), using the same word Vitruvius uses to describe the Doric column; Barbaro also describes it as strong [*fermo*] (229), like the Doric column, which has the most strength [*fermezza*] (164) of all the orders. In his commentary on IV.1, where Vitruvius describes the proportions of the architectural orders, Barbaro explains that modern architects should feel free to adapt their conventions just as musicians often adapt theoretical laws in performance. See Barbaro 1567, 165.

horizontal levels under the audience seats. Each should be tuned so that it will resonate with the sounds coming from the orchestra by sympathetic vibration, at a specific pitch of the musical scale.[35] He details different designs for their placement in small and larger theatres.[36] The design for the small theatre contains a single row of thirteen vaulted chambers separated by twelve equal intervals, with bronze *echea* placed inside. The *echea* tuned to the highest sounding pitch [*nêtê hyperbolaiôn*] are located in the outermost cavities, and from there *echea* tuned to pitches mostly descending by fourths are placed in the inner cavities until the centre is reached, where the *hypatê hypatôn* is set.[37] For larger theatres, Vitruvius suggests dividing the theatre into three horizontal rows, one replicating the arrangement of chambers in the small theatre, the other two containing chambers with *echea* emitting pitches from the chromatic and diatonic *genera*. Each of the bronze vessels, as in the design for the small theatre, is arranged with the highest pitches on the ends and the lowest in the middle. Vitruvius is also attentive to the way the various *echea* relate harmonically to each other. He explains that the architect must leave the central position of the chromatic row empty because after the chromatic pitches have been spent in pairs 'there is no other quality [of note] among the sounds in the chromatic genus that can create harmonies with the rest'.[38] In his attention to the positioning and ordering of the *echea*, so that each row of the theatre builds only musical consonances, the architect is not unlike the composer who arranges harmonies within a musical composition. At the end of these directions, Vitruvius invokes Aristoxenus:

> [...]If anyone wants to bring these directions to completion with ease, please note the diagram at the end of the book, drawn according to the principles of music. Aristoxenus, with all his dedicated enthusiasm, devised this diagram with the tunings divided by type, and has left us this legacy. And anyone who truly pays attention to his reasoning will be

35 The *echea* thus serve as what modern acousticians call Helmholtz resonators, named after a similar device invented in the 1850s by German physicist Hermann von Helmholtz. A simple demonstration of how a Helmholtz resonator works can be achieved by blowing over the top of an empty bottle, causing the air inside to vibrate and thus emit a pitch. See Ballou 2013, 111.

36 See Landels 1967, Poulle 2000 and Hagel 2009, 251-5.

37 As Hagel 2009, 251 explains, this row is 'associated with *harmonia*', referring not to the pitches of the enharmonic *genus*, but rather to the 'fixed' notes of the so-called Perfect System. In this row, Vitruvius excludes the lowest pitch, the *proslambanomenos* but includes the *nêtê synêmmenôn.*

38 V.5.5. See Landels 1967, 88-89.

> more easily capable of using the principles of Nature to design theatres that enhance the voice for the pleasure of the audience.[39]

Acoustical design relies on the principles of musical composition to enhance auditory experiences.[40]

Vitruvius concedes that he 'cannot provide any examples in Rome' of buildings containing *echea*, but points to the 'provinces of Italy' and 'Greek cities' for evidence of the use of *echea*.[41] The archaeological record is far from conclusive, but some outstanding examples may support this claim.[42] An account in 1586 by Onorio Belli of the theatre at Lyttus on Knossos describes three rows of cells with thirteen bronze *echea* in each.[43] Its location is now unknown, making it impossible to confirm Belli's account, but excavations at the theatre of Gioisia Ionica, on the coast of Reggio Calabria, have uncovered remains that also appear to be *echea* of the sort Vitruvius described. The original construction of this theatre dates to late second-century or early first-century BCE, although it was converted later in the first century into a Roman theatre. Clay vessels were found in small walled-up niches in the proscenium and back row of seats, arranged so that their mouths faced the orchestra. In the back of the podium wall, thirteen slots containing terracotta tubes terminate at the pavement level. It is unclear whether these vessels were installed in the original theatre or during a later alteration, but either way, there is a remarkable agreement between the arrangement of these vessels and Vitruvius' *echea*.[44]

A recent acoustical study suggests that Vitruvian *echea* would have been functional. Polychronous et al. (2013) devised a computer simulation model, based on Onorio Belli's 1586 description of the remains of the theatre of Lyttus, to measure the acoustical effects of bronze *echea*. They found that the *echea* do not significantly amplify the sound, but they have the strong effect of boosting the balance between early and late sound ("Centre Time").[45] Spectators sitting nearest the vessels would thus have perceived just the sort of 'increased clarity [*auctam claritatem*]' that Vitruvius describes.[46] Vitruvius obviously did

39 V.5.6. I am indebted to Andrew Barker for pointing out that this diagram is probably not the work of Aristoxenus himself, but an addition by a later writer.

40 Hagel 2009, 255: '[…] the specific design reported by Vitruvius perfectly suits the general requirements of Roman Imperial music'.

41 V.5.8.

42 See Saliou 2009, 387-409.

43 See Falkener 1854, 19.

44 See Sear 2006, 146 and Saliou 2009, 397-399.

45 Polychronopolous 2013, 67.

46 V.5.3.

not have modern acoustical tools at his disposal to test his claims; instead, he justifies his argument by analogy and extrapolation, based on his view that the tasks of the musician and architect are interrelated and fundamentally similar. As Vitruvius explains about instrument building:

> Nature, therefore, distinguished the intervals of tones and half tones and tetrachords in the voice, defined their terms by quantitative measures, and established their qualities through certain distinct modes. Using what has been established by nature, the craftsmen who make musical instruments plan their finished construction with an eye to their effectiveness at producing harmony.[47]

Like the maker of musical instruments, the architect should be attentive to the musical laws codified by Aristoxenus, so as to 'be more easily capable of using the principles of nature to design theatres that enhance the voice for the pleasure of the audience'.[48] Likewise, musical performers 'when they want to sing in a higher key, turn toward the stage doors and thus avail themselves of the harmonic support that these can provide for their voices'.[49] The architect constructing a theatre of masonry, stone, or marble, which do not resonate like wood, similarly uses structural contrivances—the *echea*—to exploit the theatre's acoustical qualities, so that the voice 'poured forth from the stage[,] … strikes the hollows of the individual vessels on contact, stirring up an increased clarity and a harmonic complement to its own tone'.[50]

The laws of *harmonia* are also necessary for determining the basic theoretical framework that governs the geometrical blueprint of the theatre. As Vitruvius explains in V.6.1:

> Whatever the size of the lower perimeter, locate a centre point and draw a circle around it, and in this circle draw four triangles with equal sides and at equal intervals. These should just touch the circumference of the

47 V.4.4.

48 V.5.6.

49 V.5.7.

50 V.5.3. Vitruvius also discusses the importance of good acoustical design for enhancing public speaking. In V.2.2, he explains that the senate house should be: 'encircled by cornices of fine woodwork or white stucco, exactly halfway up. Without these cornices, the voices of those debating in the senate house, carried upward, cannot be understood by their listeners. But when the walls are encircled by cornices, the voice, as it rises from below, will be delayed before it carries upward on the air and dissipates; it will be intelligible to the ears'.

> circle. By these same triangles, astronomers calculate the harmonies of the stars [*convenientia astrorum*] and the twelve heavenly signs in musical terms [*ex musica*].

Vitruvius is inspired by Greek philosophical tradition to believe that astronomy and music theory are founded on analogous numerical and proportional relationships;[51] he has already explained in I.1.16 that '[…] astronomers and musicians discuss certain things in common: the harmony of the stars, the intervals of squares and triangles, that is, the [musical] intervals of fourths and fifths [….]'. The theatre should thus reflect the harmonies of the cosmos in its physical dimensions while also enhancing the musicality of the audible harmonies of theatrical recitation and musical performance.[52] A well-measured architectural structure, as Vitruvius here shows, should reflect *mousikê* in ways that are perceptible to both the ear and the eye.

IIc Practical Applications: *Machinatio*

The laws of *harmonia* also play an important role in the construction and maintenance of mechanical devices used in war. When discussing the construction of *ballistae*, catapults, and *scorpiones*, which Vitruvius first introduces in I.1.8, he uses musical explanations to describe how these machines should be structured, expressly comparing the catapults to stringed instruments:

> Next the ends of the ropes are threaded in through the spring holes [*foramina*] of the capitals, and carried across to the other side, and then they are fastened around the windlasses and wound around them, so that when the ropes are stretched over them by the levers, when struck with the hand, each of them will give off a corresponding tone. Then they are secured with wedges at the spring holes so that they cannot uncoil. Thus, carried across to the other side of the capital, they are stretched with handspikes on windlasses until they make an identical sound, and in this way catapults are adjusted to tone [*ad sonitum … temperantur*] by

51 Saliou 2009, 225.

52 Poulle 2000 suggests by way of a comparison to Plut. *De anim.* 1029b that the *echea* at the Theatre of Mummius Achaicus are arrayed so as to effect "a musical reproduction of the sky as it is displayed during a Moon eclipse" (37).

> propping with wedges according to the musical sense of hearing [*musicis auditionibus*].[53]

He uses the phrase *ad sonitum . . . temperantur* to explain the system for adjusting a siege engine so that it will project a missile as intended; the connection to tuning a stringed harp or lyre is explicit. In I.1.8, Vitruvius writes about the 'hemitone spring holes' [*foramina hemitoniorum*] through which the 'twisted sinew cords' [*e nervo torti funes*] must be stretched. The word *foramina* also refers to the hole at the end of the organ pipe in X.8.5, and *nervus* is the common word for a musical string on an instrument. Vitruvius describes himself in I.Praef.2 as a famous authority on ballistic machinery, employed by Augustus to outfit catapults and repair other war machines [*ad apparationem ballistarum et scorpionum reliquorumque tormentorum refectionem*]; presumably, he speaks from years of experience when he counsels that these devices must be tuned to the right pitches like musical instruments and argues that the accuracy of their adjustment is best measured according to the evidence of a musically sensitive ear.

At the end of *De Architectura*, in X.8, Vitruvius turns to the design of actual musical instruments, detailing how to construct a water organ [*hydraulus*, in Greek usually *hydraulis*] that follows principles of Greek music theory. The *hydraulus* was frequently played in Rome and was particularly admired for its beautiful tone and powerful sound: Cicero likens its sound to the beauty the eye enjoys when beholding flowers, and some sources describe similar organs as audible more than a mile away.[54] The Vitruvian *hydraulus* has far greater performance capabilities than many earlier versions described by Ctesibius and Heron of Alexandria, containing as many as six or eight ranks and enabling the performer to perform in 'all the different varieties of tunings [*modulorum*] in music'.[55] The multiple rows of pipes are embedded within a headpiece fitted over the hydraulic mechanism called the *kanôn mousikos*—*kanôn* is the same term used to refer to the monochord used by theorists of the Pythagorean school to calculate musical intervals. The *kanôn mousikos* of the *hydraulus* here serves a practical function, finally making the laws of *harmonia* that are also useful for architectural theory audible to all through musical performance.

53 X.12.2.

54 Cic. *Tusc.* III.18.43. See Perrot 1965, Hyde 1938, and Hagel 2009, 364 for more about the *hydraulus* in antiquity and a description of the remains of a water organ found at Aquincum.

55 X.8.6. See Hyde 1938 and West 1992, 114-8.

Beyond these two practical examples, however, *harmonia* plays a fundamental role in the construction of the basic principles of mechanical theory, or *machinatio*. Vitruvius proposes that *machinatio* requires the emulation of nature and physics in order to develop mechanisms that make life convenient, and that the most important natural phenomenon to emulate is 'the revolutions of circles which the Greeks call *kuklikê kinêsis* [κυκλικὴν κίνησιν]'.[56] Vitruvius identifies the primary source of natural *kuklikê kinêsis* as the rotational patterns of the cosmos:

> Every mechanism has been created by nature and devised with the rotation of the cosmos as its teacher and governess. First let us take note and observe the continuous nature of the sun, the moon, and the five stars; if these had not been geared to rotate, we would not have had the alternations of light and darkness all this time, nor the maturation of the crops. Therefore, when our forebears [*maiores*] 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. Thus they arranged some things to be more convenient by making machines and their rotations, and some instruments, and thus what they found useful in practice they took care to improve, step by step, with the help of study, craftsmanship, and tradition.[57]

Vitruvius here, in order to be as emphatic as possible, cites the two authorities he believes are most important—the *maiores* and nature itself. *Machinatio*, then, is 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 of inspiration.

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56 X.1.1. See ps.-Aristot. *Mech.* 847a for a strikingly similar description of *kuklikê kinêsis* and mechanics: 'Remarkable things occur in accordance with nature, the cause of which is unknown, and others occur contrary to nature, which are produced by skill for the benefit of mankind. For in many cases nature produces effects against our advantage; for nature always acts consistently and simply, but our advantage changes in many ways. When, then we have to produce an effect contrary to nature, we are at a loss, because of the difficulty, and require skill. Therefore we call that part of skill which assists such difficulties, a device'. The natural movement that the skilled mechanical designer must exploit is circular motion, as explained in 847b: '[n]ow the original cause of all such [mechanical] phenomena is the circle, and this is natural[....]'. The correspondence between this passage and Vitruvius' similar discussion in *De Architectura* was noted as far back as in the Renaissance (see Barbaro 1556).

57 X.1.4.

But as Vitruvius also knows from his study of Greek philosophy, the rotation of the celestial bodies themselves is governed by music. As discussed, Vitruvius has cited these theories in both I.1.16 and in V.6.1, explaining that the geometrical arrangement of the theatre resembles a map of the musical harmonies of the cosmos.[58] Thus, the motion of orbiting planetary bodies, which Vitruvius posits as the main source of *machinatio*, is in turn commanded by *mousikê*, 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.

III The Cosmic *sambuca*

In VI.1, Vitruvius presents a curious analogy likening the natural world to a perfectly tuned Greek *sambuca*.[59] By transposing the triangular shape of a *sambuca* onto a map of the universe, and orienting it so that the lower strings rest in the north and the higher pitches in the south, Vitruvius finds that 'the whole plan of the cosmos, because of its inclination, has been composed as consonantly [*consonantissime*] as possible according to harmony by the modulation of the sun'.[60] This model explains the different physical features of the Northern and Southern races: those from Northern nations have 'moist tones of voice' that resonate specifically at the lowest pitches [*ad hypatas et proslambanomenon*]; those from the South 'express the slender sound of their voices in the highest tones [*paranetarum <netarum>que acutissimam sonitus vocis perficiunt tenuitatem*]'. The Romans, located 'at the centre of the cosmos', have a 'middling pitch to their voice in conversation'.[61] Since they possess both the most temperate voices and the most temperate climate, Romans are ideally situated to take command over all nations: 'the divine intelligence established the state of the Roman People as an outstanding and balanced region—so that it could take command over the earthly orb'.[62] The entire cosmos is thus laid out according to musical principles, 'as, for example, in a musical diagram

58 See Section IIb and Saliou 2009, 225.

59 West 1992, 76 describes the shape of the *sambuca* as a "primitive arched harp"; see also Mathiesen 1999, 275-280.

60 VI.1.6. My translation here differs from Rowland 1999, who suggests 'by modulating the sun'.

61 VI.1.7.

62 VI.1.11.

[*uti in diagrammate musico*]'.[63] This image of the cosmos expresses how all of what could loosely be termed human 'architectures'—including the structures of anatomy, physiology, and even social interactions between different races—are constructed according to the laws of music theory, reinforcing the relevance of *musice* for architectural theory and practice.

What is Vitruvius' source for this analogy? This passage does not correspond directly to any extant earlier writings.[64] One possible interpretation is that Vitruvius was alluding to a Greek musical theoretical concept, often adopted by the Aristoxenists, which explains that the central pitch of the musical scale, or *mesê*, is the 'leader [*arkhê*]' or 'guide [*hêgemôn*]' because on the string instrument it served as the fundamental pitch to which all others could be tuned in harmony.[65] This provides a logical explanation—albeit a rather unusual one—for why the Roman people who speak at a 'middling' pitch matching the intonation of the central string of the *sambuca* are apt commanders.

In this elaboration of the Aristoxenian concept of the *mesê*, Vitruvius also appears to draw on the ideas and writings of Greek philosophers, including Hippocrates and Aristotle. Both philosophers would have been included in the education of any sophisticated Roman: Hippocrates is expressly identified in I.1.13 as one of the authors in the educational program Vitruvius prescribes for the ideal architect. Like Hippocrates, Vitruvius believes that buildings should be oriented so as best to accommodate the particular vicissitudes of hot and cold winds. He also follows Hippocrates' concept of 'environmental determinism',[66] dictating that physical differences and intellectual capabilities are shaped by the qualities of local airs and waters. In Parts V and VI of *On Airs, Waters, and Places*, Hippocrates argues that people who live in cities designed to accommodate breezes in summer and the rising sun in winter, and to use clean water sources, are likely to have a superior temperament and intellect, fewer diseases, and easier childbirths.[67] Dwellers in cities not designed to complement the airs, waters, and orientations of their local environment are pale, weak and subject to disease.[68] The orientation of a city also affects the pitches at which its inhabitants speak: those from well-designed cities have voices that are 'clear' [λαμπρόφωνοί], a timbral quality associated with higher pitches, while those living in unhealthy conditions have 'low' voices [βαρυφων[οί]].

63 VI.1.7.

64 See Rowland 1999, 256 and Callebat 2004, 82.

65 See Hagel 2009, 117-22.

66 See Isaac 2006, 60-69.

67 Hippocr. *Peri aer.* V.4.

68 Ibid., VI.3.

Vitruvius also seems to follow Aristotle when he posits a metaphorical connection between the sound of a stringed instrument and the human voice. Aristotle explains in *De Anima* 420b: 'Now voice is a kind of sound belonging to something alive, for no inanimate thing has a voice, but is said to do so by way of a metaphor, as are the *aulos*, the *lyra*, and all other inanimate things that are capable of prolongation, melody, and articulation. They are like voice, because voice has these features too'.[69]

It is impossible to be certain whether Vitruvius read the original texts of either Hippocrates or Aristotle, especially since it was common for Latin authors to rely on summaries in Latin of earlier Greek texts. Some commentators hypothesise that the theories in VI.1 are drawn from a Roman writers such as Varro or Frontinus,[70] and there are striking similarities between VI.1.4 and Pliny's *Natural History* II.189.[71] Nevertheless, as Callebat concludes, evidence often suggests that Vitruvius is also relying on Greek texts.[72] Either way, whether Vitruvius tended to read his sources in the original Greek or in Latin translation, he relies on a tradition of reading Greek authorities that reflects his education in the elite system of study he refers to as *encyclios disciplina*, and whose intellectual models were Greek.

IV Vitruvius and the *encyclios disciplina*

The term *encyclios disciplina*, as Doody 2009 explains, is linked to the Greek term *enkyklios paideia* and is also discussed in other Latin encyclopaedic texts, including Pliny's *Natural History* and Quintilian's *Institutio Oratoria*. While in Hellenistic Greece it may simply have referred to the ordinary educational system for young men, comprising a fixed set of disciplines and philosophical areas of inquiry meant to be studied in a specific order, by Vitruvius' time it was no longer an everyday term and required definition.[73] In I.1.3, Vitruvius outlines the fields of enquiry that every architect must study:

69 Arist. *De an.* 420b. See also ps.-Aristot. *Pr.* XIV, which discusses the effects of climate on bodily and mental capabilities, and *Pr.* XI, which discusses the effects of bodily temperature on the emission of pitch.

70 See Callebat 2004, 71.

71 Callebat 2004, 72.

72 Cf. Callebat 2004, 74.

73 Doody 2009, 13.

> To be educated, he must be an experienced draftsman, well versed in geometry, familiar with history, a diligent student of philosophy, know music, have some acquaintance with medicine, understand the rulings of legal experts, and have a clear grasp of astronomy and the ways of Heaven.[74]

He goes on in I.1.13 to cite the authorities in each of these fields, naming Aristarchus (philology), Myron and Polycleitus (sculpture), Hippocrates (medicine), and Aristoxenus (music)—all of them Greek. Although his list of subjects and authors is so vast as to be 'aspirational',[75] in I.1.14-16 he explains that the architect need not 'achieve full mastery' in all different fields; this is because the *rationes* of every discipline rely on the same set of common principles. He uses music as an example, showing how it shares theories in common with both medicine and astronomy. The implication is clear: if the theoretical rules of music can be applicable to fields as different as these, they can be applicable to architecture as well.

In Augustan Rome, this system of education was available only to men of elite status; as Masterson 2004 suggests, Vitruvius' description of the architect's education was part of "a strategy that made the architect an estimable man, someone to be taken seriously".[76] Architecture, as a paid profession "in the opinion of the elite, was staining and servile",[77] but by describing an education "whose authorizing power both makes him impressive intellectually and assimilates him to his social betters, [Vitruvius] consolidates his claim to being an estimable personage".[78] This educational system was not intended to prepare young minds for a life of labor or intellectual struggle, but rather for the 'pleasure' to be enjoyed by philosophical reflection and inquiry. The architect trained in the well-rounded *encyclios disciplina* is the intellectual equal of any member of elite society, equipped to rise above the indignity of manual labor and perhaps even to enter the ranks of the upper class.

As Masterson shows, VI.Praef. allows Vitruvius to "focus and negotiate further" these key issues of status, pay, and pleasure, as moderated by his discussion of the ideal *encyclios disclipina*, by telling the story of the Greek

74 I.1.3.

75 Doody 2009, 13.

76 Masterson 2004, 391.

77 Ibid., 388.

78 Ibid., 393. Doody 2009, 13: "the more impressive the breadth of *enkyklios paideia*, the more exalted the subject [must be]".

philosopher Aristippus.[79] Washed up on the beach of Rhodes after a shipwreck, Aristippus discovers a series of geometric diagrams drawn on the sand. He heads straight to the gymnasium to engage in philosophical debate, where he is rewarded with gifts. When Aristippus is asked to return, he quips that all men should be given enough possessions [*possessiones*] to be so fortunate as to be shipwrecked in Rhodes. These *possessiones*, Vitruvius writes, are education: for he who is educated is a 'citizen in every country'.[80] Vitruvius thanks his parents for educating him 'in accordance with the spirit of the Athenian law' in an art 'that cannot be mastered without education in letters and comprehensive learning in every field'.[81] Vitruvius delights to find that education is 'the greatest reward of all: that there is no need to have more, for true wealth is to want nothing'; thus, he never strove in his field to make money, but simply to pursue 'modest means and a good reputation'.[82] As Masterson 2004 shows, Vitruvius proposes an equivalence between the architect and the philosopher, who both hold intellectual *possessiones* granted to them by Greek education; the architect who works because he delights in it attains a higher status than that of the mere craftsman, who must struggle for pay and is skilled only with his hands.

The cosmic *sambuca* analogy of VI.1 immediately follows this passage, and it illuminates the important role music plays in the *corpus* of intellectual disciplines included in the *encyclios disciplina*. Just as any student of *encyclios disciplina* should do in a philosophical debate, Vitruvius cites and combines a wide range of Greek authorities—and, in this case, arrives at an idiosyncratic vision of cosmic order arranged according to the principles of music theory. Music is a key part of Vitruvius' conception of cosmic and architectural forms because it is also a key part of a Greek-style education. Music also shares its theoretical principles in common with a wide variety of disciplines—including architecture, as the whole of *De Architectura* clearly demonstrates. Vitruvius' treatise thus offers a unique expression of the essential role of music theory in ancient Roman intellectual life, as a field of primary interest to architects and others who are well-educated, able to discover within music the secrets to the architectural forms that they both encounter in nature and create themselves.

79 Ibid., 387.
80 VI.Praef.2.
81 VI.Praef.4.
82 VI.Praef.4-5.

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