ARCHITECTURE IN MOTION: A MODEL FOR MUSIC COMPOSITION

By

JORGE ELIAS VARIEGO

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To my family

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Abstract of Dissertation Presented to the Graduate School
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ARCHITECTURE IN MOTION: A MODEL FOR MUSIC COMPOSITION

By

Jorge Elias Variego

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Speculations regarding the relationship between music and architecture go back to the very origins of these disciplines. Throughout history, these links have always reaffirmed that music and architecture are analogous art forms that only diverge in their object of study. In the 1st c. BCE Vitruvius conceived Architecture as "one of the most inclusive and universal human activities" where the architect should be educated in all the arts, having a vast knowledge in history, music and philosophy. In the 18th c., the German thinker Johann Wolfgang von Goethe, described Architecture as "frozen music".

More recently, in the 20th c., Iannis Xenakis studied the similar structuring principles between Music and Architecture creating his own "models" of musical composition based on mathematical principles and geometric constructions.

The goal of this document is to propose a compositional method that will function as a translator between the acoustical properties of a room and music, to facilitate the creation of musical works that will not only happen within an enclosed space but will also intentionally interact with the space. Acoustical measurements of rooms such as reverberation time, frequency response and volume will be measured and

systematically organized in correspondence with orchestrational parameters. The musical compositions created after the proposed model are evocative of the spaces on which they are based. They are meant to be performed in any space, not exclusively in the one where the acoustical measurements were obtained.

The visual component of architectural design is disregarded; the room is considered a musical instrument, with its particular sound qualities and resonances. Compositions using the proposed model will not result as sonified shapes, they will be musical works literally "tuned" to a specific space. This *Architecture in motion* is an attempt to adopt scientific research to the service of a creative activity and to let the aural properties of enclosed spaces travel through music.

> 'We have two ways of positing the outside world.
>
> Numbers. Through their effect there is a plurality of individuals: sympathy, order harmony, beauty, etc. [...] in short, everything that is of mind.
>
> Space. This gives us objects "having extension"
>
> In the spatial world the images of the numerical world are projected, first by nature itself, then by men and above all by artists. It can be said that our duty on earth and during the whole of our life consists precisely in this projection of forms issued forth from numbers, and that you, the artists, fulfill that moral law to the highest degree. Not only is it possible to appeal simultaneously to geometry and to numbers, but to do so is the true purpose of our life.'
>
> Andreas Speiser

CHAPTER 1
DELIMITATION OF THE OBJECT OF STUDY

Overview

This document proposes a model for musical composition, a set of rules that govern the creative process. Those rules are established prior to the music composition and are the framework for the imagination and creativity of the music composer.

This systematic organization of rules by no means intends to limit the creativity of the artist, instead, it is proposed as an "open" model that provides general guidelines for the elaboration of a piece of music. Those guidelines are "particularly elaborated" and based upon data collected from the acoustical properties of enclosed spaces. The architectural acoustic properties of rooms provide constant values that afterwards become dynamic through music. In Iannis Xenakis's words in *"Le modulor II"*[1]: "Goethe said that "architecture was music become stone". From a composer's point of view the proposition could be reversed by saying that "music is moving architecture".

In the same line of thought, but in the realm of architecture, Le Corbusier[2] proposed in *Le Modulor* an "open" model for architectural design based on the golden section contained in human proportions. The pillar values of his system are (in centimeters) 226, 113, 70 and 43 which come from the measurements of an "average" man; also, according to the model, 113-183-226 define the occupation of space by a man six feet high.[3] Those values have a golden mean relationship and follow the Fibonacci series.

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[1] Le Corbusier (1955), *"Le Modulor II",* 326-327.

[2] Le Corbusier (1948), *"Le Modulor".*

[3] Ibid. 65-66.

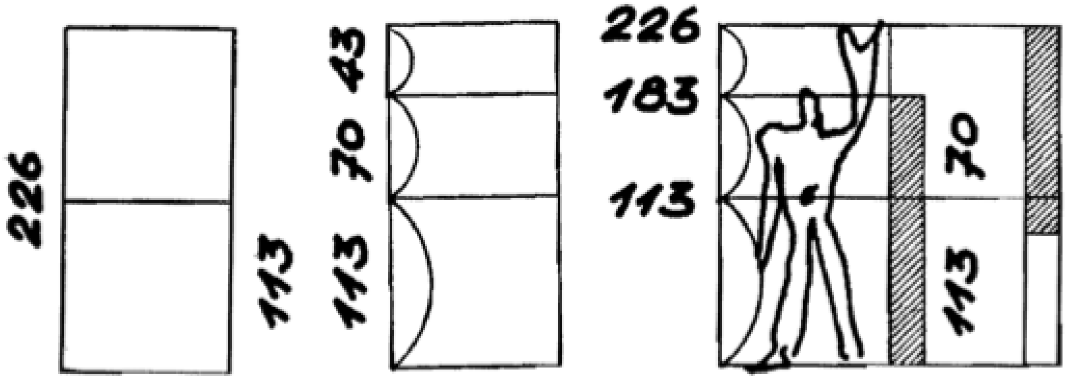

Figure 1-1. The human proportions according to Le Corbusier's *Le Modulor.*

This model was a new measurement system that was not based on the meter nor the foot and their subdivisions. Le Corbusier proposed a model to standardize the design of buildings for humans based on human proportions. He believed that the traditional metric systems were artificial and "dislocated" from human needs; "[…] the meter, indifferent to the stature of man, divisible into half meters and quarter meters, decimeters, centimeters and millimeters, any number of measures, but all indifferent to the stature of man, for there is no such thing as a one-meter or a two-meter man". [4] Le Corbusier's proposition is not a matrix but a set of guidelines of scale and proportion for the standardization of building construction. The proposed model in this study is not a recipe for "mass composition" but a tool to develop a creative process that is not indifferent to architectural acoustics. The creative process begins with data collection that is then translated – through the model – into musical terms, which are organized in time as a musical composition meant to be performed. The uniqueness of this sequence resides in the fact that its first and last steps are essentially aural; it begins by

[4] Ibid. 21-22.

quantizing a sonic experience that at the end of the process becomes sound again, the model goes from sound (measure) to sound (performance).

The acoustical measurements are the starting point of the model and need only to be taken once; the application of those measurements could vary. For example, a number of different chords result from the same frequency centroid value obtained from a room. As in any model, the artistry is revealed by its application, not by the model itself. This initial set of numbers is musically meaningless before it is projected through the model.

Likewise, Le Corbusier initiates his reasoning by accepting the concept of an "average man" to obtain the desired measurements. His model and the buildings constructed after it would be completely different if he had chosen an "ideal" human being with a dissimilar body size and proportions from the one he ultimately chose for his model. In his anthropomorphic approach to architectural design, Le Corbusier first had to decide on the most suitable representation of a human being, measure it, and construct a model after it. It is here important to state that Vitruvius, in the 1st c. BCE, had already thought the order of classical architecture connected with man, its relations with buildings and with the cosmos.[5] He also based his theory on the human figure, creating the well-known "Vitruvian man" which would later become popular in the Renaissance through a drawing by Leonardo da Vinci.

Despite that fact, Le Corbusier's method is still unique because of its pragmatic application and goal, to standardize the constructions of houses. Vitruvius - instead - had a purely ideal objective, which was to perpetuate through architecture the perfectly

[5] Pollio Vitruvius,*"The ten books of architecture",* translation by Ingrid Rowland (1999).

harmonic proportions of man as a scaled representation of the harmony between the planets.

The aim of the study I propose is not to find the room with the finest acoustical properties for music composition and to create works after it. On the contrary, the purpose is to provide the composer with a set of versatile tools to translate acoustical data from “any” enclosed space into music. Space and sound are inseparably bound, the music finds its meaning in the space which, at the same time, becomes a unique musical source. These concepts together open up the artist’s compositional palette, not only conceiving a piece of music as a mere succession or progression of sonic events through time, but also as a spatial journey. The structure of the composition becomes three-dimensional, letting the artist apply data from one or more spaces, suggesting a transit between them by means of their acoustical properties, or even utilizing computer software to create their own ad-hoc “aural” designs.

Far from being a literal translation of an architectural plan into music, the proposed compositional model has specific characteristics. In architecture, the model is an actual scaled representation of the finished construction, an identical copy of the final piece. That scaled representation of the original can only generate more versions that merely replicate the original. On the other hand, the compositional model I propose operates in a different way; identical acoustical data can be implemented by the same composer to generate an infinite number of works that do not resemble each other. It is an open algorithm that can produce diverse results depending on the decisions made by the composer. Similarly, a single twelve tone row could be the model for many compositions.

Like a piece of music, a prospective building in an architectural plan could change its character depending upon the context where it is constructed (performed). Imagine the same studio room built identically in two different environments, one in the epicenter of an over-crowded city area, and the other in a rural area. Despite the correspondence between the two constructions, their meaning and function become “clashing concepts”. The former is an efficient administration of space where the architectural design successfully balances the specific issues of housing, location and size of the room, the latter being a wasteful one in which the housing needs and room size do not address its location. The ideas of context and re-contextualization take part in the proposed model; compositions created using this model re-contextualize the acoustical space by means of the elements of a foreign space incorporated in the music. A composition based on acoustical measurements from a room *x* is performed in room *x,* in that case being “tuned” to it and reinforcing its aural properties; if this same composition is performed in room *y* then the acoustical properties of that room get re-interpreted and re-contextualized through the music that has embedded properties of a different space in a sort of “crossed resonance”. The listener experiences the aural attributes of room *x*, where the music is performed, filtered through the attributes of room *y* that are incorporated in the music. In Blesser’s[6] terms, the listener experiences a “sonic illumination” of a room with the colors of another one.

That illumination takes place when the physical processes of a space get excited. When processes such as interference, reflections, shadowing, dispersion, absorption, diffraction and reverberation are activated by means of a sonic impulse (music, noise,

[6] Barry Blesser and Linda Ruth Salter (2007), *“Spaces speak, are you listening?”,* 17.

people talking, etc.) the listener receives multiple acoustic cues to aurally visualize objects and the spatial geometry.[7] A simple wall, for example, is perceived as a visual boundary of the enclosed space and also as a sound reflective surface that provides the listener with aural cues for location (within the space), volume, and materials of the room.

The dichotomy for the architect is that he needs to handle both "visual" and "aural" architectures simultaneously, as they are interdependent. A window could add luminosity and enhance the sensation of volume of a space but at the same time could have undesired aural consequences by letting outside sounds filter through it. The architect decides whether to add that window or not in his plan, a visual tool that merely projects the geometric properties of a space though it is unable to reproduce the space's response to sound. Room response can be calculated precisely but its aural representation is elusive for the architect who mostly relies on visual cues. "To communicate the artistic, social, emotional and historical context of a space, architects almost exclusively consider the visual aspects of a structure. Only rarely do they consider the acoustic aspects. The native ability of human beings to sense space is rarely recognized […]"[8]

Consequently, a natural question arises: is an architectural plan the most efficient representation of the aural architecture? The architectural plan is in the realm of visual architecture; proportions, distribution of the elements within the construction, design (shapes) and measurements are perceived and represented visually. The role of the

[7] Ibid. 17.

[8] Ibid. 1.

architectural designer here is – in general terms – to create and administer a physical space. On the other hand, the aural architecture refers exclusively to the human experience of a sonic process. As Barry Blesser defines it "[…] aural architecture refers to the properties of a space that can be experienced by listening."[9] The architect is in charge of that listening experience and is also solely responsible for it. Therefore, the plan becomes a deficient tool to project the acoustic properties of a space.

In this proposed model the aural element is the key factor; architecture is deprived of its tangible and visual components, becoming a discipline of pure sonic perception, blurring even more its differences with music. That listening experience within a room is quantized and re-sonified by the composer who becomes an "architect of sound". The composer employs only the visual queues and values that are relevant to measure, explain and reproduce the aural experience.

Volume of Orchestration. Samuel Barber's *Adagio for Strings Op. 11* and Giacinto Scelsi's *String Quartet No. 4*

Can the music composer effectively represent space in a musical score? A musical score has the same limitation as the architectural plan: it provides a limited visual representation of the succession of the sonic events in time. If we consider Samuel Barber's *Adagio for strings* in its original setting for string quartet (1936)[10] and its later version for string orchestra (1938)[11], we can clearly appreciate that the differences between the two scores are minimal, which by no means reflect the singularity of each version. In other words, it is impossible to visualize in the musical

[9] Ibid. 5.

[10] Samuel Barber (1936), *"String quartet Op. 11",* G. Schirmer.

[11] Samuel Barber (1938), *"Adagio for strings Op. 11",* G. Schirmer.

score the magnitude of the aural changes of Barber’s re-orchestration. The larger orchestrational volume of the version for string orchestra elongates the resonances and multiplies the dynamic range of the ensemble, suggesting a larger “space” within the music. The apparent simplicity of the re-orchestration of the *Adagio* has two relevant consequences that deserve further analysis.

Volume of Orchestration and Chorus Effect

Volume of orchestration[12] could be defined as the amount of input sources in a chorus effect that modulate reciprocally. In Barber's *Adagio* the duplication of the individual voices (in a string orchestra) has that specific result, which occurs when individual sounds with roughly the same timbre and nearly the same pitch (due to performance imperfections) converge and are perceived as one. No matter how well trained a group of string players may be, they do not tune nor vibrate identically and they never perform the same pitch in impeccable unison. So the random, unpredictable phase cancellations that occur as a result of these slight pitch differences are the source of the chorus effect. The volume of orchestration is, then, a way to measure the amount of sound sources used to generate a chorus effect.

The version of the *Adagio* for string orchestra produces this effect acoustically as each musical line is imperfectly “doubled” by multiple similar sound sources (individual instruments of the orchestra). Regarding the generation of the chorus it is important to mention that the effect can also be simulated using electronic effects or a signal processing device. It is achieved by combining multiple copies of a sound - each one delayed and pitch shifted slightly differently - and mixed with the original undelayed

[12] Dante G. Grela H., *“Análisis Musical: una propuesta metodológica”,* (to be published by the editorial of the Universidad Nacional del Litoral, Argentina).

sound. This can be done by continual slight random modulation of the delay time of two or more different delay taps. It is clear that the electronic simulation of the effect approximately reenacts the physicality of the original acoustic result. Regardless of the technology or form factor, the processor achieves the effect by taking an audio signal and mixing it with one or more delayed, pitch-modulated copies of itself. The pitch of the added voices is typically modulated by a Low Frequency Oscillator (LFO).

Similarly to the concept of physical volume, the volume of an orchestration reflects the “thickness” of a line - which is considered as a three-dimensional object - and the amount of space it occupies. The following example from the first bars of Barber’s *Adagio for Strings* would have an orchestrational volume of one if its was performed with string quartet, or of eight if that same line was played by a string orchestra with eight first violins.

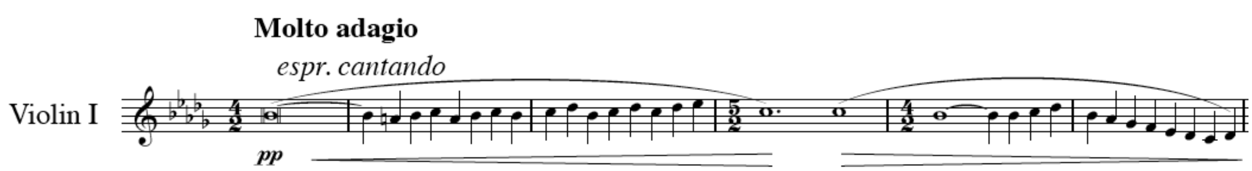

Figure 1-2. Excerpt from measures 1- 6 of the violin I part of Barber’s *Adagio for strings Op. 11.*

This concept becomes relevant when considering the consequences in dB of the addition of sources of equal level. The level of the previous excerpt performed with a solo violin (volume 1) increases in 9 dB when it is performed by a string section of eight players (volume 8) with the same dynamic.

The orchestrational volume can be a dynamic value if it changes through time or non-dynamic if it changes abruptly. That change can be achieved gradually (by means of a crescendo or a decrescendo) or abruptly by simply adding an extra instrument with the same dynamic indication.

Table 1-1. Adding sound sources of equal level.[13]

Number of sources of equal level	Level increase in dB	Orchestrational volume
1	0	1
2	3	2
3	4.8	3
4	6	4
5	7	5
6	7.8	6
7	8.5	7
8	9	8
9	9.5	9
10	10	10

The following examples show a practical application of those possibilities. The first excerpt shows a dynamic orchestrational volume value that increases from 1 to 2 by means of a crescendo.

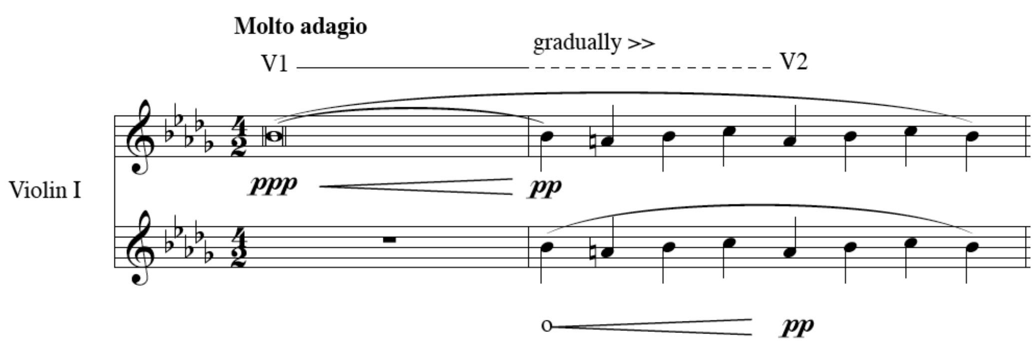

Figure 1-3. Excerpt from measures 1 - 2 of the violin I part of Barber's *Adagio for strings Op. 11,* reworked to show a gradual increase in the orchestrational volume.

[13] M. David Egan (1988). "*Architectural acoustics",* 23.

The second example shows a non-dynamic change of orchestrational volume (from 1 to 2) by the simple addition of one instrument to the line.

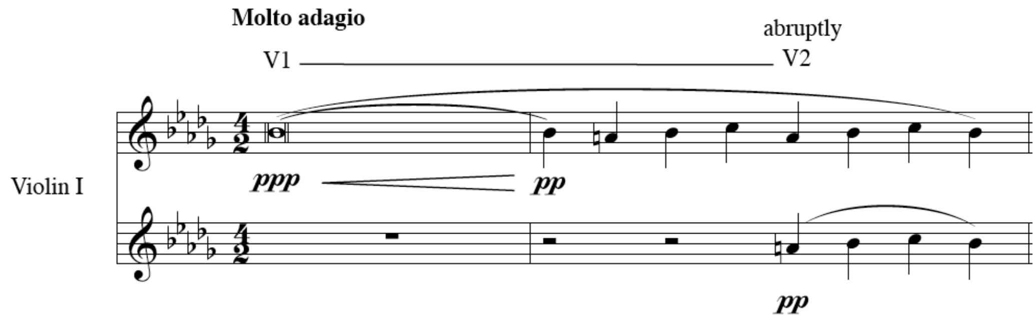

Figure 1-4. Excerpt from measures 1- 2 of the violin I part of Barber's *Adagio for strings Op. 11,* reworked to show a non-gradual increase in the orchestrational volume.

Chorus is the resulting effect of the doublings and the levels of volume of orchestration are a numerical way to quantize them. Regarding this topic, it is inevitable to consider the work of Giacinto Scelsi.

Figure 1-5. Volume of orchestration: Giacinto Scelsi *String quartet No. 4* m. 5 – 9.

The excerpt on Figure 1-5, from measure 5 – 9 of his *String Quartet 4,* exemplifies his extremely limited pitch vocabulary and his deep commitment to spectral variations through the orchestrational volume. The whole passage is built throughout upon two groups of instruments (violins I and II, and violin II and viola) orchestrated with volume 2. The two groups are an octave apart on a Cb4 (in the violins) and a Cb3 (in the violin II and the viola), both with a very active polyrhythmic texture.

It is interesting to appreciate Scelsi's concern about spectrum and color. He calls for a "scordatura" or non-traditional tuning for the strings in order to achieve a unique color due to the unusual tension given to the strings. Each string is conceived as a different musical instrument with its own tone. None of the open strings of the two violins match in pitch; furthermore, the composer specifically assigns an individual stave per string to perform specific passages. The use of orchestrational volume is the core of this work, where the listener is required to be extremely alert in order to appreciate sounds that evolve within other sounds of near-identical pitch. Those pitch centers together with the spectrum changes controlled by the use of micro tonality and volume of orchestration, define the overall formal arc of the composition.

Xenakis also considered the subject in his *Formalized Music*, where he dissects all properties of sound in order to, possibly, reconstruct it using electronic means. Those small variations of spectral lines in frequency as well as in amplitude are, in his point of view, of great importance as they make the difference between a lifeless sound made up of a sum of harmonics produced by a frequency generator and a sound of the same sum of harmonics played on an orchestral instrument.[14]

[14] Iannis Xenakis, *"Formalized music",* (1971), 244.

The essential components of the electronically generated chorus tend to capture and replicate the inconsistencies of the human performers through the consistency of electronic media. Those elements are: a) random delay time, between 20 ms and 50 ms, so the original and delayed sources are aurally perceived as a single source; b) frequency shift (LFO); c) amplitude modulation. Those microscopic imperfections appear ubiquitously in the string version of the *Adagio,* creating a new sonic dimension - unique in every performance - that can be hardly quantized but can be analyzed and visually appreciated through a sonogram.

The following examples are sonograms of the spectral changes of a single pitch with and without a chorus. The two examples could easily correspond to the two orchestrations of Barber's *Adagio.* The partials of the fundamental tone are well defined in both examples, but the amount of inharmonicy (spectral components that do not correspond to a harmonic partial) is clearly dissimilar.

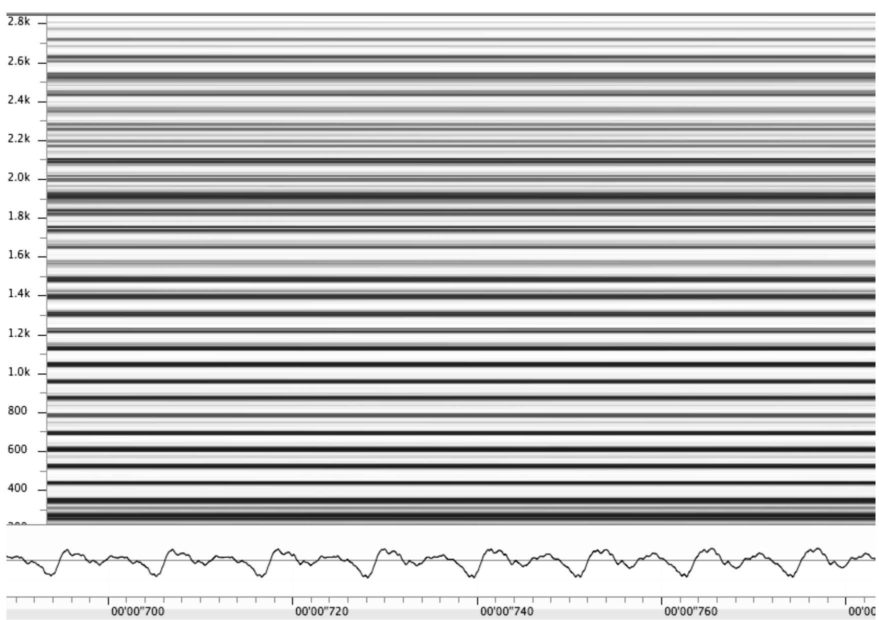

Figure 1-6. Sonogram of an F2 on a cello without chorus (single instrument).

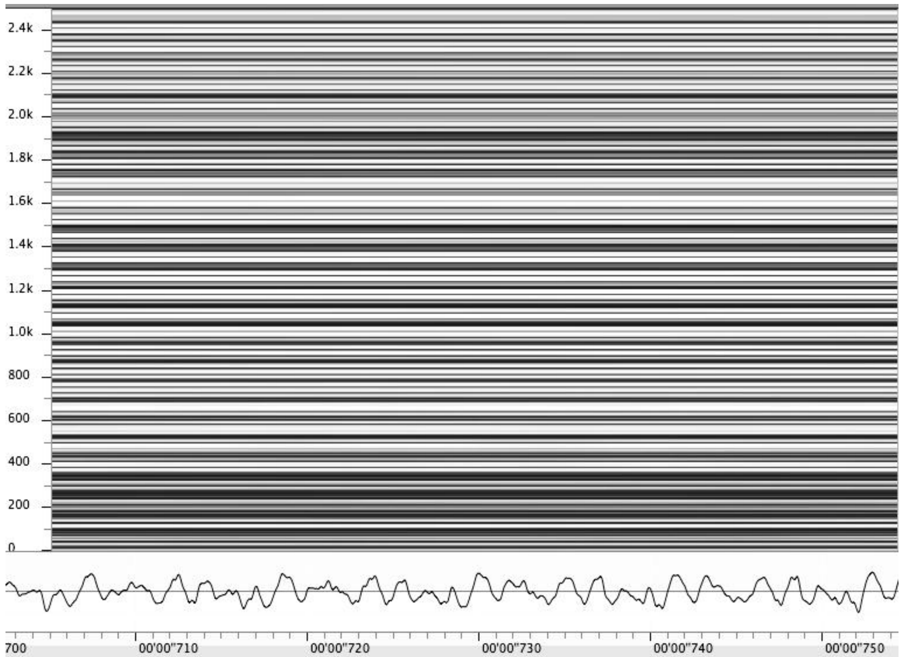

Figure 1-7. Sonogram of an F2 on a cello with chorus (cello section).

The increased richness in the spectrum and the irregularity of the wave (as a result of the modulation) are the most evident consequences that can be visually appreciated in the sonograms. Delay time is also one of the main components of this effect. In a large ensemble, those concatenated delay lines inevitably blur the attacks and note changes compromising the overall intelligibility of the musical material. As will be discussed later, a slower tempo is the natural solution for conductors to regain clarity.

Addition of the Double Bass and Expansion of the Frequency Range

Doubling the bass line with double basses and cellos is a common resource that Barber utilized in his orchestration. For the most part, the double bass reads the same part as the cello, sounding an octave below. That basic re-orchestration has relevant spectral consequences. First, the frequency range is considerably expanded: Barber asks for a double bass with an extended range to the low C1, which opens the spectrum a whole octave below the cello range, roughly covering the whole range of human hearing (from 20 Hz to 20 MHz). Despite that fact, Barber avoids the open C1 in the basses (he never uses it throughout the work) in order to stay away from the roughness of the open string and to keep the drama "alive" through his orchestration.

Secondly, the bass does not double the entire cello part. In m. 13-14 the two cello lines in *divisi* and the double bass play in unison reinforcing the stepwise descending line, momentarily "thickening" the cello section. In addition to that, the section without basses has a thinner, more "airy" texture full of drama (m. 28) that somehow prepares the climactic moment of m. 54 in the extreme high register. Paradoxically, the basses rest during that section and the string orchestra becomes a string quartet with an increased orchestral volume, achieving the utmost tension of the work not with a *tutti* but with an extreme rise of the spectral content of the ensemble.

Volume of Orchestration and Tempo

It is also important to state that all of the recorded versions of the Adagio for string orchestra are at least 50% longer than the versions recorded with string quartet, reaffirming the idea that the orchestrational volume added by the large ensemble embeds an impression of a larger physical space into the music.

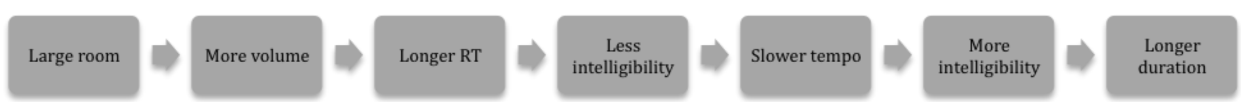

Figure 1-8. Larger instrumentation influence in tempo and duration.

The conductor's choice for a slower tempo is a natural reaction to the spatial qualities implied by the larger volume of orchestration: a larger space suggests a bigger physical volume that - according to Wallace Sabine's formula - generates a longer reverberation time[15], which consequentially lowers the intelligibility index. In order to recover that intelligibility, the conductor decides on a slower performance tempo. This is the ultimate reason for the longer duration of the version for string orchestra. This link between orchestrational volume and musical tempo is an example of the implied relations between orchestration and time, but is not utilized as a parameter in the proposed model. However, the proposed model is not indifferent to the RT values, which are consistently translated into duration and enveloping in the music domain.

The Proposed Model and Spectral Composition

The paradigm of spectral music composition is similar to the proposed model. In both cases the compositional decisions are preceded by the analysis of a sound source. Spectral composers focus on the qualities of timbre and utilize mathematical analysis techniques, like the Fast Fourier Transform among others, in order to obtain a clear description of the components of the sound source. Despite its many aesthetic variants, the core of spectral composition (for traditional instruments and/or electronic media) is the focus on timbre and its spectral components.

The similarities with the proposed model are clear; both systems begin with a type of sound analysis, which provides the platform for musical artistry. In spite of that analogy, the systems are dissimilar regarding their final objective. On the one hand, spectral composers search for the combination of qualities of a complex sound that define its color and make it unique; on the other hand composers utilizing the proposed system can seek the color of a room manifested through sound, and for all other

[15] M. David Egan (1988). "*Architectural acoustics", 63*. Sabine's formula establishes a direct relation between room volume and RT. $T = 0.05 * V/a$

properties of an enclosed space that somehow influence the sonic event. Those properties come from various sources: impulse-response studies, architectural plan, form and structure of the space, materials utilized in the construction, and many others.

Equivalences and Terminology

One of the first issues of this model is the translation between the perceived change of the dynamic of a sound (in the music domain) to its parallel in the realm of room acoustics, a variation in sound pressure level measured in decibels. For practical reasons each dynamic indication is assumed to be perceived by the listener as twice as loud as its previous one: ***mf*** is perceived as twice as loud as ***mp*** which is perceived as twice as loud as ***p***. That relation is accurate within performance[16] practice and facilitates the translation of musical dynamics into decibels. This is supported by the widely spread theory of psycho-acoustic pioneer Stanley Smith Stevens.[17] It indicates that the doubling or halving the sensation of loudness corresponds to a level difference of 10 dB or one dynamic level.

The softest and highest values of the “overall range” according to Table 1-2 correspond to the lowest and highest levels of sound pressure that those instruments can produce. The samples are from instruments with an extended dynamic range that also represent each of the instrument families.

Those equivalencies represent the frame for the translation of sound pressure values from room acoustics into musical terms (that are non-numerical). As an example, a hypothetical room with a G factor (the ratio in dB between the energy of the direct

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[16] According to Marcel Tabuteau’s number system as explained by David McGill in *“Sound in Motion. A Performer’s guide to Greater Musical Expression”.* (2007). 71.

[17] Stanley Smith Stevens (1957). “*On the psychophysical law”.* Psychological Review 64(3): 153–181

sound and the energy of the reverberated one) of 60 dB would result in a passage orchestrated in ***p***.

Table 1-2. Dynamics equivalences in dB.

Dynamic indication *(musical notation)*	Meaning	Decibels
ppp	*Pianississimo* – extremely soft	40
pp	*Pianissimo* – very soft	50
p	*Piano* – soft	60
mp	*Mezzo piano* – medium soft	70
mf	*Mezzo forte* – medium loud	80
f	*Forte* – loud	90
ff	*Fortissimo* – very loud	100
fff	*Fortississimo* – extremely loud	110

The following table shows the dynamic range (expressed as sound level pressure in dB) of a representative group of musical instruments. The measurements were taken from a distance of 10 ft.[18]

Table 1-3. Instruments dynamic range in dB.

Instrument	Softest (in dB)	Loudest (in dB)
Cymbal	40	110
Organ	35	110
Piano	60	100
Trumpet	55	108
Violin	42	90
Overall range	35 - 40	108 -110

[18] Online resources: Marshall Chasin, *"Hearing aids for musicians".* http://www.generalhearing.com/explore.cfm/chasin/ and Geoff Husband http://www.tnt-audio.com/topics/frequency_e.html

It is important to mention that the sound pressure level range of musical instruments (in the domain of architectural acoustics) is translated to its most analogous parallel in the realm of music composition (as a dynamic range). The application of the proposed compositional model is discussed in depth in Chapter III. The following classification and definitions are based on the ones proposed by Leo Beranek[19].

1- Dimensional:

V = volume of the hall in cubic feet or meters.

H = average room height, this value is needed to calculate the time of the first ceiling reflection.

W = average width, important to determine the intimacy of the room.

L = average room length, useful to determine the magnitude of the decrease of sound with distance.

2- Acoustical:

RT = reverberation time in seconds.

EDT = early decay time in seconds.

Bass ratio: ratio between the RT at octave center frequencies of 125 Hz and 250 Hz, and octave center frequencies 500 Hz and 1000 Hz (between low and mid-high frequency bands).

IACC = interaural cross-correlation coefficient. Measures the difference in the sounds arriving at the two ears of the listener. That coefficient can be calculated with or without frequency weighting.

[19] Leo Beranek (2004), *"Concert halls and opera houses", 576 – 580.*

ITDG = initial time delay gap, is the amount of time, measured in milliseconds, between the direct sound and the arrival of the first reflections.

C80 = clarity factor. Ratio between the energy perceived by the listener within the first 80 msec. of an impulse and the remaining energy of the sound after the 80 msec. It is expressed in dB.

LG = lateral energy. Measures the ratio between the direct sound and the one reflected from the sides and is also expressed in dB.

G = the ratio in dB between the energy of the direct sound and the energy of the reverberated one, indicating the “loudness” of the room, also called “strength factor”.

CHAPTER 2
INTERRRELATIONS BETWEEN MUSIC AND AURAL ARCHITECTURE THROUGH HISTORY

Overview

This section is a chronological study of the interrelations between music and architecture through the examination of paradigmatic works. Concrete applications implemented by artists – both architects and music composers – are studied as well as their influence on other creative disciplines. The chosen works respond to the main object of this study as they are somehow related to properties of aural architecture that influenced music composition as well as musical parameters that influenced architectural design.

Polio Vitruvius, the *Ten Books of Architecture* (1st c. BCE)[20]

In *Book I* of his *Ten Book of Architecture*, Vitruvius discusses the importance of the integral education of the architect who not only should be a capable draftsman but also well versed in many other disciplines like medicine, music and philosophy. This concept of the architect as a “master builder” derives from the Greek *arkhitekton*, *arkhi-* "chief" + *tekton* "builder, carpenter"; this Roman model of a “chief builder” was much broader than the one we conceive today. A modern architect is exclusively dedicated to the design, plan and construction of buildings; in the 1st c. BCE the architect was also a broad-spectrum technician who was well versed in fields that spanned from urban planning to military engineering.

“For neither native talent without learning nor learning without native talent create the master craftsman. To be educated, he must be an experienced draftsman, well

[20] Pollio Vitruvius, *“The Ten books of Architecture”,* translation by Ingrid Rowland (1999).

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." [21]

That general instruction had very specific applications. Vitruvius served as a *ballista* (artilleryman) where musical instruction became very practical when aiming catapults. The tension of the cords in the catapults was calculated by "ear", a perfect straight shot could only be achieved if the tension chords were perfectly "in tune".

> "The architect should know music in order to have a grasp of canonical and mathematical relations, and besides that, to calibrate ballistae, catapults and scorpions. In the headpieces of war machines there are "hemitone" spring holes, right and left, through which the twisted sinew cords are pulled tight by windlass and handspikes; these cords should not be wedged in place or fastened down unless they give off a particular and identical sound to the ears of the catapult maker. For when the arms of the catapult have been cocked to these tensions, upon release they should deliver an identical and equivalent thrust; if they are not tuned identically, they will keep the catapult from launching a straight shot."[22]

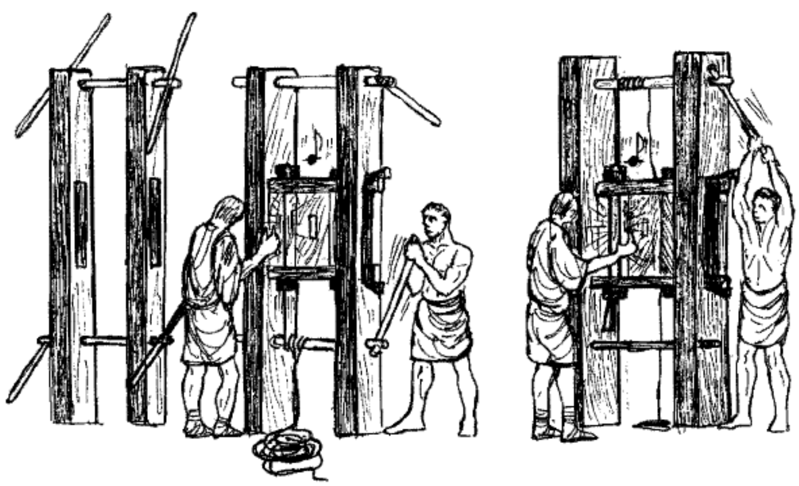

Figure 2-1. Tuning of the catapult, from the *Ten Books of Architecture.*

[21] Ibid. 22.

[22] Ibid. 23.

> "Next, the ends of the ropes are threaded in through the spring holes 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. […] They are stretched with handspikes on windlasses until they make an identical sound, and in this way catapults are adjusted to tone by propping with wedges according to the musical sense of hearing." [23]

In addition to that, in *Book V*, Vitruvius applied Pythagorean principles of harmonic ratios in the design of theatres. He implemented a "room equalization system" based on bronze or earthen vessels – called "echea" - placed under the seats of theatres, to assist, by their resonance, the voices of the performers.

This is one of the first examples of an enclosed space conceived as a musical instrument where its design features are intended to enhance specific sounds that take place within it. The *Vitruvian* theaters interact with the performers, amplifying and "equalizing" the sounds of their on-stage performances. In figure 2-2 we can clearly appreciate that the tuning of the room is not indifferent to its design; small and large theaters were tuned differently.

"The harmonies that human nature can measure out are called *symphoniae* in Greek, and number six: *diastesseron* (fourth), *diapente* (fifth), *diapason* (octave), and *disdiatesseron* (octave + fourth), *disdiapente* (octave + fifth) and *disdiapason* (double octave)." [24] "In theaters, likewise, the bronze vessels – the ones the Greeks call *echea* – which are enclosed underneath the seats, are placed according to mathematical principle based on their pitch. The vessels are grouped in sections around the circle of the theater to create intervals of a fourth, a fifth and so on up to a double octave. As a

[23] Ibid. 23.

[24] Ibid. 67.

result, the speaker, as it occurs onstage, should be so located in the theater's overall design that when it strikes the *echea* it will be amplified on impact, reaching the ears of the spectators as a clearer and more pleasant sound."[25]

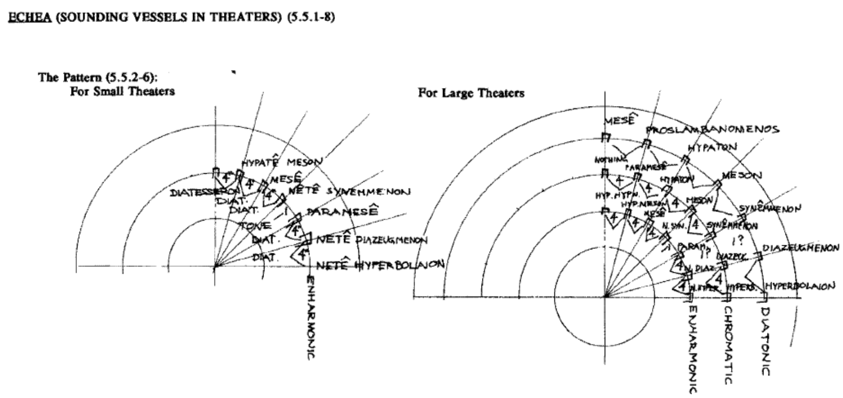

Figure 2-2. Tuning system for the vessels.

The vessel tuning suggested by Vitruvius follows the progression of the first four partials after a fundamental tone, which are also separated by a fifth, a fourth and the resulting double octave. By reinforcing the first partials of an implied fundamental he provided the space with a characteristic resonance. Like in brass instruments, that "theoretical fundamental" is the lowest possible resonance that can be obtained from an instrument - in this case an enclosed space - related to its size and length of the sound waves. That resonance is not aurally present[26] but it is the basis for the harmonic series. Vitruvius' design follows that same principle, using the vessels tuned to the first partials of a harmonic series to provide the space with a particular formant. However that approach depends almost exclusively on the richness of the spectrum of the sound performed on-stage. The pure tone of a lyre would rarely provide enough spectral

[25] Ibid. 68.

[26] John Backus, "*The Acoustical Foundations of Music",* (1969), 220 - 221.

energy to stimulate the vibration of the vessels and - on the other hand - a strong baritone voice would take true advantage of them. Following a basic acoustical principle, the *Vitruvian* vessels can reinforce properties already existing in a sound source but they are unable to generate them as there is no acoustical design capable of filling frequency "holes". "Indeed, we can observe this from performers who sing to the lyre, who, 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. When, however, theaters are constructed of more solid material, that is, of masonry, stone, or marble, which can not resonate, then they should be outfitted with *echea* for just that reason." [27]

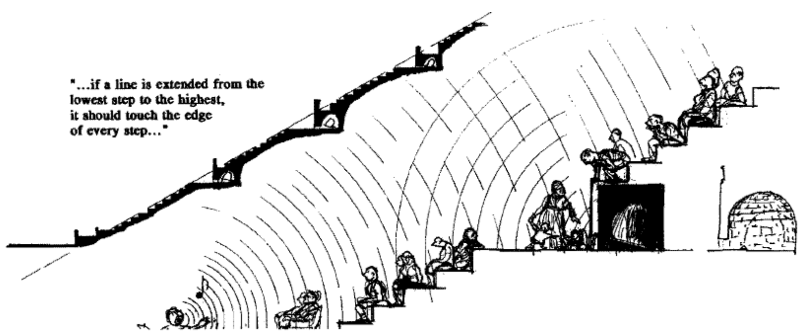

Figure 2-3. Theater ceiling and audience area suggested by Vitruvius.

It is clear that the Roman master was foreseeing two core acoustical issues of theater design: reinforcement of sounds events happening on-stage and the frequency response of the space. His solution came from a combination between the steep angle of the audience seats and the design of the ceiling (sound reinforcement) and the resonating vessels system (frequency response). "By this contrivance the voice onstage, poured forth from stage – as it were, from the center of the theater – and

[27] Pollio Vitruvius,*"The Ten Books of Architecture",* 68.

circling outward, strikes the hollows of the individual vessels on contact, stirring up an increased clarity and a harmonic complement to its own tone."[28]

Vitruvius was already considering in his designs the quality of the sound perceived by the audience in a theater. He sought a "clear and pleasant sound" and desired to provide every member of the audience with the same aural experience. Those concerns are very much current today when large audiences are the norm. In the design of theaters, aural architects have to simultaneously deal with the general acoustic properties of the space and their perception, reassuring that they propagate evenly throughout the audience area. Parameters of balance, warmth, brightness and clarity are of standard use by architects in order to measure the desirable qualities of a space designed for performance. The aural pleasure of the audience was Vitruvius's ultimate desire. Sound was his main concern in theatre design, and he strived to achieve an "ideal sound" that would please the audience members. Vitruvius translated the general harmonic proportions of sound into theater design. In other words, he made a theater a "tuned resonant body".

***Coro Spezzato,* Polychoral Style at St. Mark's Cathedral (16th c. ACE)**

The *Vitruvian* science of sound was still current in the 16th c., being based on the Greek model of sound propagation, similar to the concentric waves generated by water after dropping a stone in it. Concepts of wavelength and geometrical acoustics arrived in late 17th c. with the studies of Gaston Pardies and Isaac Newton. Until then, buildings and specifically churches were built following the lineaments of the *Vitruvian* four attributes of acoustical quality. According to them, the spaces could be: 1) *dis-sonantes*

[28] Ibid. 68.

(spaces that partially reflect the sound waves), 2) *con-sonantes* (spaces in which the environment facilitates the circulation of sound waves), 3) *circum-sonantes* (spaces in which the sound waves reflected by curved surfaces, return to their starting point creating a reverberation), and 4) *re-sonantes* (spaces that create echoes). Those attributes were purely subjective and intended for the design of open spaces like Greco-Roman theatres, showing limitations when applied to the acoustics of enclosed spaces.[29]

> "St. Mark's Cathedral follows the canons of Byzantine architecture with a complex geometric design, mosaics with sophisticated patterns, high domes, decoration with public figures and a slightly illuminated interior. The building has two singing galleries, or *pergoli,* that were erected by the Venetian chief architect Jacopo Sansovino between 1536 and 1544, located on either side of the chancel, just inside the choir screen […] Both *pergoli* are decorated with bronze reliefs of the Marcian legends by Sansovino, in each case three on the front panels and one on the end towards the rood screen. Whereas the first series displays familiar scenes from the life of the apostle, already well known to Venetians, the second presents obscure miracles supposedly performed by a saint at sites in the lagoon. This fact strongly suggests that the second *pergolo* was an afterthought, requiring considerable inventiveness to devise an iconographic *programme*. In the context of Wilaert's composition of psalms arranged for divided choirs or *coro spezzato* in these very years, it may be inferred that the left-hand *pergolo* was added in order to provide a second location for singers, spatially separated from the first."[30]

According to Howard and Moretti, there is a necessary link between Sansovino's *pergoli* design and the spatial separation of choirs in Saint Mark's cathedral. It can be inferred that the architectural design responded to a musical need. It is possible that Sansovino's design of the second *pergolo* was the natural response to Wilaert's

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[29] Deborah Howard and Laura Moretti *"Architettura e Musica nella Venetia del Rinascimento"* (2006).

[30] Deborah Howard and Laura Moretti, "*Sound and Space in Renaissance Venice: Architecture, Music, Acoustics",* (2009), 37.

experiments with split choirs, providing an architectural solution to obtain a spatial balance between the performing forces.

According to Carver's definition, "a polychoral work or passage is one in which the ensemble is consistently split into two or more groups, each retaining its own identity, which sing separated and together within a through composed framework in which antiphony is a fundamental compositional resource […]."[31]

In the 16th c. many composers in Venice applied that compositional resource which would later be one of the trademarks of the Venetian style. Among those composers, the names of Adrian Willaert and Andrea and Giovanni Gabrieli stand out as the most influential of the time.

Willaert's appointment as *maestro di capella* at St. Mark's on December 12, 1527, was a relevant event in the development of the *cori spezzati* style as he probably introduced it as a performance practice in Venice.[32] This type of composition was a real innovation in the mid 1500's, gaining popularity not only in Italy but also throughout Europe. Willaert's *cori spezzati* psalms were printed as a collection in 1550 by Antonio Gardano's printing shop; that compilation was the first publication known in the style.[33]

Gioseffo Zarlino published in 1558 a treatise in music theory called *Le intitutioni harmoniche* where he makes reference to his master's contribution regarding this type of composition: "Psalms in *chori spezzati* are arranged and divided into two choirs, or even three, each in four parts; the choirs sing one after another, in turn, and sometimes

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[31] Anthony P. Carver, *"Cori Spezzati",* (1988), preliminary notes 1.

[32] Deborah Howard and Laura Moretti, "*Sound and Space in Renaissance Venice: Architecture, Music, Acoustics",* (2009), 27-28.

[33] Anthony P. Carver, Ibid. 35.

(depending on the purpose) all together, especially at the end, which works very well. And […] such choirs are placed rather far apart." [34]

Zarlino continues addressing the interrelation between the split choirs:

> "Because such choirs are placed at some distance from each other, the composer should be warned (so that he is not displeased by dissonance amongst the parts of any of them) to compose the piece in this manner, that each choir be consonant; that is that the parts of one choir be ordered in such a way as if they were composed simply for four voices without considering the other choirs, having nevertheless regard in the placing of the parts, that they accord with one another, and there be no dissonance. So that [with] the choirs composed in such a manner, each one would be able to sing separately, and one would not hear anything, which might offend the hearer. This advise is not to be despised, because it is very useful; and it was discovered by the most excellent Adriano [Willaert]".[35]

Those compositional recommendations made by Zarlino in his treatise are not indifferent to Willaert's compositional style, which relied on the spatial attributes of St. Mark's Cathedral. Simple and clear harmonies with a slow pacing help reveal the acoustical space for which those compositions were intended.

The utilization of acoustical space was not a mere coincidence; according to Zarlino each choir should be harmonically self sufficient and consonant, complementing each other to produce a pleasant sensation on the listener. In addition to that, Zarlino in his work makes specific reference to the treatment of the bass parts in relation to the spacing of the choirs. The spatial separation of the choirs could easily generate undesired chord inversions, like 6/4 for example, due to the fact that singers might not be able to perceive the true bass of the harmony. In order to counterbalance this potential problem, Zarlino makes a series of suggestions for the composer, which tend

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[34] Gioseffo Zarlino, *"Le Institutioni Harmoniche",* (1558), 268.

[35] Anthony Carver, Ibid. 10.

to overcome the arising problems of two groups of singers that perform in synchronicity but are placed far from each other.

The following example shows how, according to Zarlino, the bass lines for a composition for two spatially separated choirs should be treated. The intention here is to conceive the bass line as a single line (for the most part) that works as the basis for both choirs, which are independent from each other. The comparison between the two basses is clear enough, octaves and unisons work together, outlining and reinforcing the actual single bass line that unifies both choirs.

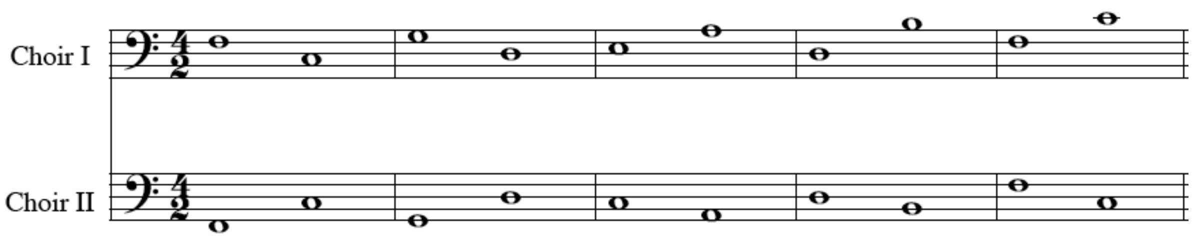

Figure 2-4. Example of *basso sequente* according to Zarlino.

Like Vitruvius, composers in the 16th c. - particularly Willaert - were also concerned about the listener’s aural pleasure within the enclosed space. Towards that goal Willaert utilized clear harmonies and sophisticated textures, based on a thoughtful spacing between the individual voices. That approach can be seen in the following example from *Domine Probasti Me (Ps. 138)* by Willaert for two choirs. The first excerpt shows an economic use of counterpoint, with a primarily homorhythmic texture and an antiphonal interaction between the two groups. The overlapping between the two choirs is only two beats and with the same chord (with almost identical voicing), which facilitates the crossover between separated ensembles. The bass line is also composed following Zarlino’s guidelines.

Figure 2-5. Excerpt from measures 5 - 12 from Willaert's *Domine Probasti.*

The next example, also from *Domine Probasti,* corresponds to the final *Alleluia* of the psalm. The contrapuntal activity here is noticeably increased but not obtrusive, each line preserves its individuality within the texture. The very few non-harmonic tones that appear contribute to create momentum towards the end of the work. The bass line is a *basso sequente* between the two choirs, mainly built upon octaves and unisons between the two groups, also doubling, in the very end, the *cantus firmus* that is carried by the tenors of choir I.

Tenors and basses from both choirs emphatically affirm the plagal cadence by moving almost exclusively within the sonorities of F and C major. In Wilaert's psalms the pitch contrast is not large, and indeed is more a question of chord spacing, since choir one always contains the highest and lowest voices, giving choir two a closer spacing. One might speculate that it was the latter to which the four solo singers were assigned in Saint Mark's, certainly closer spacing makes the blending of solo voices easier to obtain.[36]

Figure 2-6. Excerpt from the final Amen, measures 222 – 300 from Willaert's *Domine Probasti.*

Carver suggests that the blending within the choirs was also considered by Willaert in his works, who supported the idea that a large ensemble of voices was most likely to produce a fused sound despite the internal separation of the voices. On the other hand choirs with one singer per part needed to be scored in closer position in order to achieve a unified sound.[37]

According to Howard and Moretti, the average RT in Saint Mark's Cathedral is 4.8 seconds,[38] which could explain Willaert's economy and clarity of means; his stylistic

[36] Ibid. 37.

[37] Ibid. 35 - 37.

[38] Deborah Howard and Laura Moretti, Ibid. 244

fingerprints were homophonycally contrasted with note against note polyphony, concise imitative points, syllabic writing with controlled *melisma* towards the cadence.[39]

On the other hand, Rufino d'Assisi, who served as *maestro di capella* at the Padua Cathedral in 1510, had a different approach to the use of spaced choirs, and with different results. In his *Missa Verbum bonum* there is an unbalanced relation between tuttis and antiphony.[40] The large overlapping between the two choirs produces many parallel octaves as well as dynamic peaks instead of smooth cross fades between the successive entrances. That fact becomes even more relevant if we consider the reverberation decay: Willaert used it [RT] as a smoothing device between groups, on the contrary, Ruffino actually composed the cross fades between the entrances. Rufino's approach has acoustical deficiencies if we consider the aural consequence of the addition of sound sources of equal intensity in dB. If we hypothetically consider that each choir has 4 members (one on a part) each of them singing at 75 dB, we have a level of 81 dB per choir. When the choirs overlap (like m. 4 of the example) the overall level is increased in 3 dB for three beats as a consequence of the addition of the voices of the second choir. This acoustical consequence is perceivable by the listener and has relevant compositional implications: each of the choir entrances creates a dynamic "bump" obstructing the overall continuity of the spatial and linear development of the composition. This fact, added to the poor quality of the part writing and the RT of the space, results in a mostly blurred and unclear musical result.

[39] Anthony Carver, Ibid. 39.

[40] Ibid. 24.

Figure 2-7. Excerpt from Ruffino's *Verbum bonum.*

Willaert's approach is, to a certain extent, the opposite. His eight polychoral settings in *I salmi* are scored for two separate choirs, the first of which delimits the overall range of the work while the second fills in the middle of the texture. The psalm text is distributed equally between the two choirs, which present alternate verses or half-verses. Compared to the more exuberant settings of earlier as well as later composers [Ruffino, Gabrielis respectively], Willaert's settings are reserved and austere in style, adopting the expressive character, mode, melodic material and cadential articulations of the plainsong psalm tones. The two choruses sing together only rarely, primarily near the cadences that mark the verse endings or in the final doxology.[41]

Willaert's psalm *Cum invocarem* is a perfect example of how the spatial performance of the work complements the simplicity of the writing. "They [the choral exchanges] reveal a sensibility to the text where […] the words *A fructu frumenti, vini et olei* [By the fruit of corn, of wine and oil] are set to marvelous 'floating' chords which

[41] Michele Fromson, *Oxford Music Online*.

reveal a consummate grasp of the expressive possibilities of simple triads alternated by groups of subtly differing composition."[42] The aural stereophonic effect is reinforced by a "chordal" stereophony that "colors" the text and also stimulates a harmonic binaural experience in the listener. The progressions are self sufficient in each choir but not necessarily create a smooth voice leading between the two ensembles. The voice leading from the choral exchanges is quite angular and generates parallel successions (i.e. the parallel fifths resulting from the successive entrances of the choirs in measure 3 of the excerpt). It can also be appreciated how Willaert solved the issue of continuity and intonation between the two choirs using a *basso sequente* structured upon the roots of the tonic and the dominant chords. The relevancy of Willaert's work in the realm of the relations between musical composition and aural architecture is undeniable. His intuitive contribution was based on the clarity and economy of means in his music, which complemented the attributes provided by the acoustics of St. Mark's Cathedral.

Figure 2-8. Excerpt from Willaert's *Cum invocarem.*

[42] Ibid. 39.

After Willaert’s death, in 1562, Andrea Gabrieli was appointed organist at St. Mark’s, which for some authors demarked the beginning of the Venetian style. Rich sonorities, colorful harmonies and the lively interplay of forces that started to appear in Wilaert finally emerge in the works by Andres and Giovanni Gabrieli.

Claude Debussy – Color, Shapes and Proportions in *La Mer* (1909) and Other Works

Theories that assert Debussy's intentional use of mathematical proportions in his works remain as mere speculations for many reasons. Works like *La Mer* and *Estampes* show distinctive structural attributes that suggest Debussy's unequivocal use of mathematical ratios such as the Golden Section and the Fibonacci series. However, those compositions are not obvious regarding the intentional or intuitive approach by the composer. These two systems of balance and proportion are pillars of the French Symbolist movement with which Debussy was very much associated towards the end of his student days. At this time, the composer spent more time among writers and painters than with fellow musicians.[43]

As a reaction against naturalism and realism, symbolism was among the anti-idealistic movements, which attempted to capture reality in its rough distinctiveness, and to elevate the humble and the ordinary over the ideal. Symbolism began with that reaction, favoring spirituality, the imagination and dreams.

Symbolist poets believed that art should aim to capture more absolute truths, which could only be accessed by indirect methods. Thus, they wrote in a highly metaphorical and suggestive manner, endowing particular images or objects with symbolic meaning. In the symbolists’ *Manifesto,* Jean Moréas, who published the

[43] Ray Howat, *“Debussy in proportion. A musical analysis”,* (1983), 163.

document in 1886, proclaimed that symbolism was adverse to "plain meanings, declamations, false sentimentality and matter-of-fact description", and that its goal instead was to "clothe [sic] the ideal in a perceptible form whose goal was not in itself, but whose sole purpose was to express the ideal". [44]

They conceived the physical world as a collection of symbols, a language that needed to be deciphered by the spectator, where nothing has a plain meaning, everything evokes an deeper image, a metaphor. The Symbolist influence on Debussy is palpable, and of course *Prélude à l'après-midi d'un faune* was inspired by Mallarmé's poem *L'après-midi d'un faune.*

Those principles also influenced Debussy's musical perception, where the architectural design of a work and its expressivity were inseparably bound. Every note had a meaning with an enormous expressive potential. In his review on Paul Dukas' *Piano Concerto* from 1901, Debussy writes: "[...] you could say that the emotions themselves are a structural force, for the piece evokes a beauty comparable to the most perfect lines found in architecture."[45]

"Music is a series of perceptible surfaces created to represent esoteric affinities, which Symbolists used to evoke their primordial ideals." [46] In Debussy, sounds and their succession in time are indirect methods that conceal deeper meanings.

Spirals are present *La Mer* as a formal device that the composer utilizes in order to revisit certain material from the past that, and at the same time, transform it into new musical ideas that continue to develop in the same fashion. In this work, Debussy

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[44] Jean Moreas, "*Symbolist Manifiesto",* (1886).

[45] Ray Howat, Ibid. 173.

[46] Jean Moreas, Ibid.

reveals his natural tendency towards repeated visits to the same musical territory, a characteristic fixation upon specific sounds, patterns, textures, harmonic structures, sonorities, even absolute pitches and melodic fragments, resulting in what we may call aural images. “One comes to feel that Debussy's aural images are psychological links between certain works of his; they are signs of his unremitting perfectionism, in that, always doubting his own accomplishment, he may have attempted to pursue some forever-elusive musical idea by resurrecting it in another work turning his whole compositional output into a spiral.”[47]

Musical proportions and numerical experiences could have also come to Debussy through his Baudelaire readings, especially his essay *Du vin et du hachish* in which the poet describes a particularly vivid experience of music as numbers, intimately related to *La Mer's* spiraled construction.

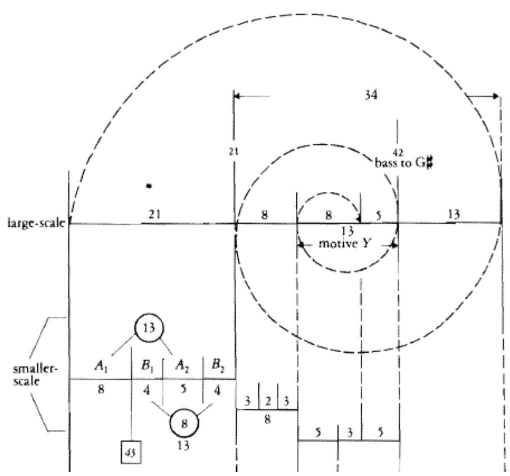

Figure 2-9. Spiraled form of *La Mer* according to Howat.

The first edition of *La Mer* appeared with a reproduction on the cover, at Debussy's request, from Katsushika Hokusaki's print *The hollow of the wave off Kanagawa*, a copy

[47] Mark De Voto, *“Debussy and the Veil of Tonality”,* (2004), 24.

of which also hung on Debussy's study wall. The dominating motive of the print is the wave, whose lower outline curves in logarithmic spiral, admittedly broader than Debussy's variety. In addition, the golden section divisions indicated around the picture shows how close the composition comes to overall GS, especially if we consider the upper extremity of the wave, the side of its lower curve, and the top of Mount Fuji.[48] Those curves and extreme points of the waves are actual mathematical functions (if *x* and *y* axis are added, for example) that Debussy transplanted into form and the development of his musical ideas. A similar concept of translations of functions into music will be seen later on in this chapter, in the section about Xennakis.

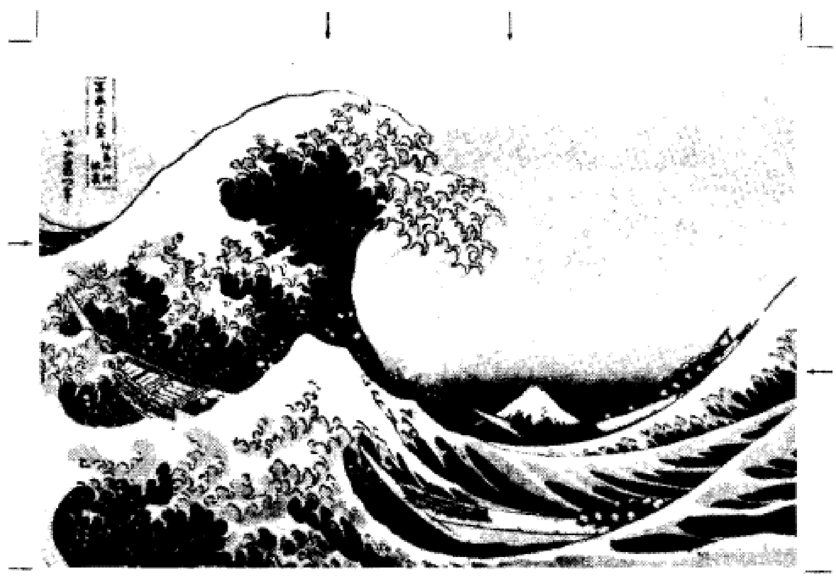

Figure 2-10. Katsushika Hokusaki's *The hollow of the wave off Kanagawa*.

> “Despite those facts, none of Debussy's surviving manuscripts contain any signs of numerical calculations concerning structure. This, however, is inconclusive, and also not surprising. Most of these manuscripts are the final copies given to the engraver, an artist as meticulous as Debussy was over the visual presentation of his scores, both manuscript and printed, would hardly have been so unprofessional as to deliver his finished product

[48] Ray Howat, Ibid. 178.

> with scaffolding still attached. In any case, these final copies are mostly third or fourth drafts of the works concerned, by which stage their forms would be well established. Apart from these final copies, only a very small number of sketches have survived. Debussy is known to have destroyed the large majority of his sketches, and, while that proves neither side of the question, it could be conjectured that the few sketches which remain are those that divulge no secrets [...] No firm conclusion can be drawn from the above."[49]

Debussy was deeply aware of the numerical connotations of music composition, but it is still uncertain if he used them intentionally or not. "Music is a mysterious mathematical process whose elements are a part of infinity".[50]

"In addition to that, it can be said that Debussy was completely unaware of his proportional systems. His subconscious judgment was responsible for organizing them with such precise logic and he would later have had to completely avoid the possibility of such occurrences in his later works."[51] That awareness is confirmed if we compare the similar use of proportional schemes that appear in *La Mer* and *La Cathédrale Engloutie* two works that are considerably distant in Debussy's career.

Additionally, the use of a center of resonance as a compositional device is another example of Debussy's reinterpretation of his ideas throughout his production output. His *Prélude à l'après-midi d'un faune* from 1895 (one of his most remarkable early works) undoubtedly circles around the pitch class C#; *L'isle joyeuse*, from 1905 (from his middle period), recurrently plays around the initial pitch class C#; *Syrinx* from 1913 (in his late period) is, for the most part, constructed around the initial pitch class Bb. These three works have a very similar initial harmonic and gestural structure and spanned

[49] Ray Howat, Ibid. 6.

[50] Ibid. 171. Debussy (1977), 199.

[51] Ibid. 162.

throughout all Debussy's compositional periods. This conceptual material seems to be revisited and reinterpreted, exemplifying Debussy's natural tendency towards self-recycling. This arabesque ornamentation around a given pitch class is one of Debussy's trademarks.

1 - Excerpt from a solo piano version the first bars of *Prélude à l'après-midi d'un faune* (1895).

Figure 2-11. Measures 1-3 from *Prélude à l'après-midi d'un faune.*

2 - Excerpt from the first bars of *L'isle joyeuse* (1905).

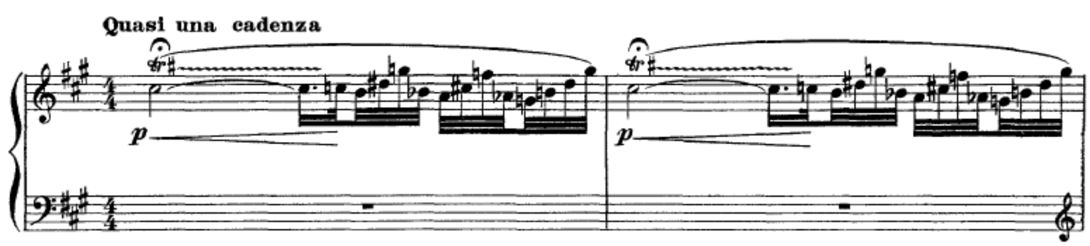

Figure 2-12. Measures 1- 2 from *L'isle joyeuse.*

3 - Excerpt from *Syrinx* for solo flute (1913).

Figure 2-13. Measures 1- 2 from *Syrinx.*

Similarly, the idea of Debussy using such scientific means of formal regulation (consciously or not) is quite incompatible with his known distaste for musical formulas, which at the same time were conceptual examples of “plain meanings”, quite unwelcome among the Symbolists. Literally, a formula is a prescribed method, convention or recipe, nothing metaphoric - a definition applicable to such construction as fugue, sonata form and so forth.[52] Debussy desired to evoke images and spirituality through his music and these self-explanatory processes were not a suitable tool.

Even though Debussy's search for perfection in his scores is documented in some of his letters where he specifically expresses concern about golden section proportions. In a letter of August 1903 from Debussy to his publisher Jacques Durand, returning the corrected proofs of the *Estampes*, Debussy writes:

"You'll see, on page 8 of *'Jardins sous la pluie'*, that there's a bar missing - my mistake, besides, as it's not in the manuscript. However, it's necessary, as regards number; the divine number, as Plato and Mlle Liane de Pougy would say, each admittedly for different reasons".[53]

The difference in proportion between the final score and the Sibley manuscript of *De l'aube a midi sur la mer* makes clear that the music was not composed to fit rigid plans impervious to any subsequent modification.

> “If Debussy was applying GS consciously, the plans could evidently be remodeled according to other musical demands, many of which may have been primarily instinctive ones, however consciously carried out and perfected eventually. The point again is that Debussy would never have set his intellect on the rampage without simultaneously applying his intuitive judgment. If alternatively, he was completely unconscious of the proportions

[52] Ibid. 9.

[53] Ibid. 7.

> just seen, we are left with awkward logic. This is because the Sibley manuscript, even in its final state, does not have overall GS coherence and the final score has. This would mean, therefore, that Debussy's proportional intuition failed him entirely with the large-scale dimensions in the Sibley manuscript, and then suddenly brought the form to virtually maximum accuracy in one fell swoop […] involving a changed tempo relationship that happily provided exactly the necessary dimensional adjustment."[54]

Ray Howat has traced Debussy's use of mathematical proportions in detail. Even though, few analyses of Debussy's music consider dynamic shape at all, and those that do, tend to focus only on isolated aspects such as the principal climatic point of a work.[55] Nevertheless dynamics are a vital structural element of Debussy's mature music. The tidal flow of swelling intensities of the dynamics, specifically in works like *La Mer*, reveals a novel programmatic method with an outstanding dramatic outcome. The tides, undulations of the waves, the wind and its shape, are metaphorically symbolized through the dynamic structure of the work which evokes particular states of mind and aural images that invite the listener to decipher them. As a vital component for the completion of Debussy's music - the listener is constantly challenged to resolve aural puzzles. What is given appears to be incomplete; the symbols need the spectator to become meaningful. "In *'Reflets dans l'eau'* the composer evokes the concentric propagation of sound waves, not only are many of the sequences [...] visibly reflected round some central musical turning point; but also their reflected portions (or images) tend to be compressed in size, giving an effect of refraction - another aspect of reflection (or deflection) in water."[56]

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[54] Ibid. 91.

[55] Ibid. 12.

[56] Ibid. 28.

Somehow anticipating Le Corbusier, Debussy was also bound to the intrinsic properties of sound explained by Pythagoras and their numerical implications. Le Corbusier used the Pythagorean theory in order to justify his own set of ideas in which he desires to import the universality of the proportions of the individual components (harmonics) of a given sound into a model for architectural design not based on the properties of sound but on the human figure and its scope. On the other hand, Debussy finds a more poetic interpretation of the ancient theory: “[...] the old Pythagorean theory that music should be reduced to a combination of numbers: it is the 'arithmetic of sound' just as optics is the 'geometry of light'.”[57]

Interestingly, his use of proportions never becomes formulaic, as it is never used in the same way twice. The similarities between Debussy’s pieces are always offset by a sharp contrast. In Debussy, the presence of spirals is always recurrent.

Le Corbusier - *Le Modulor* (1948)

The Second World War left Europe with an incalculable housing deficit. Le Corbusier, in 1948, published a method for standardized construction based on the proportions of the human body. He called it *Le Modulor* [58], and defined it as a "range of harmonious measurements to suit the human scale, universally applicable to architecture and to mechanical things." With this work Le Corbusier carried on with the tradition started in 1st c. BCE by the Roman architect Polio Vitruvius and continued by Lenardo Da Vinci in the 16th c., who sought to discover the human proportions applicable to architecture.

[57] Ibid. 171. Debussy (1977), 255.

[58] Le Corbusier started in the early 1940’s to develop a scale of visual measures that would unite two virtually incompatible systems: the Anglo Saxon foot and inch and the French Metric system.

This section of the study complements the explanation given in chapter I (delimitation of the object of study) in which a general description of Le Corbusier's method is shown. Here, specific references to music and sound phenomena in Le Corbusier's writings are addressed. The Pythagorean theory about sound components and their relations (ratios) was one of the inspirations for *Le Modulor.*

According to Le Corbusier, Pythagoras' theory was a human interference in the natural qualities of sound in order to make music permanently transmissible in another way than from mouth to ear. Sound is a continuous phenomenon, an uninterrupted transition from low to high. The voice can produce and modulate it and certain instruments, like the violin, can do the same. As there was no method available at the time to notate music, it was necessary to represent sound by elements, which could be grasped, breaking up a continuous whole in accordance with a certain convention and making from it a series of progressions. These progressions, based on certain ratios, would then constitute the rungs of a scale, an artificial scale of sounds created by man. The question here was how to divide that perfect continuum of frequencies into breakpoints, cutting up sound in accordance with a rule acceptable to all. That rule should be efficient, flexible, adaptable, allowing for a wealth of nuances and yet simple, manageable, and easy to communicate and understand.[59]

"Pythagoras solved the problem by taking two points of support capable of giving certainty and diversity: on the one hand, the human ear, the hearing of human beings,

[59] Le Corbusier, "*Le Modulor"* (1948), 15.

on the other, numbers, that is to say mathematics in all its forms: *Mathematica*, herself the daughter of the Universe."[60]

To Pythagoras, music was one of the dependencies of the divine science of mathematics, and mathematical proportions inflexibly controlled its harmonies. "The Pythagoreans professed that mathematics demonstrated the exact method by which the good established and maintained its universe. Number therefore preceded harmony, since it was the immutable law that governs all harmonic proportions. He wanted to know why some musical intervals sounded more beautiful than others, observing that when the lengths of vibrating strings are expressible as ratios of integers (e.g. 2 to 3, 3 to 4), the tones produced were harmonious."[61]

"After discovering these harmonic ratios, Pythagoras gradually initiated his disciples into this, the supreme Arcanum of his Mysteries. He divided the multitudinous parts of creation into a vast number of planes or spheres, to each of which he assigned a tone, a harmonic interval, a number, a name, a color, and a form."[62]

The Greek mysteries included in their doctrines a magnificent concept of the relationship existing between music and form. The elements of architecture, for example, were considered as comparable to musical modes and notes, or as having a musical counterpart. Consequently when a building was erected in which a number of these elements were combined, the structure was then likened to a musical chord, which was harmonic only when it fully satisfied the mathematical requirements of harmonic intervals. The Greek influence can be appreciated in Vitruvius' *Ten books of*

[60] Ibid. 15 – 16.

[61] Online resource: http://www.sacred-texts.com/eso/sta/sta19.htm

[62] Online resource: http://www.sacred-texts.com/eso/sta/sta19.htm

Architecture, when he addresses the importance of the specific orientation of the theaters in order to be in full harmony with the cosmos. In *Book III* [63] of his work, Vitruvius states that: “[...] the choice of building sites for temples, the forum, and all other public places, [should be made] with a view to general convenience and utility. If the city is on the sea, we should choose ground close to the harbor as the place where the forum is to be built; but if inland, in the middle of the town. For the temples, the sites for those of the gods under whose particular protection the state is thought to rest and for Jupiter, Juno, and Minerva, should be on the very highest point commanding a view of the greater part of the city. Mercury should be in the forum, or, like Isis and Serapis, in the emporium: Apollo and Father Bacchus near the theatre: Hercules at the circus in communities which don’t have gymnasia nor amphitheatres [...]”.

The beauty of Le Corbusier's method resides in the fact that he was able to translate the divine proportions (Golden Section and the Fibonacci series) into a fully pragmatic model for architectural design without giving away any of the essential components.

The Pythagorean theory of the harmonic overtones series and their ratios was the initial pillar that supported Le Corbusier’s desire to elaborate a method that could integrate idealism with pragmatic concepts overcoming the disparities between the Anglo Saxon and the French metric systems.

Alvin Lucier - *Chambers* (1968), *I am sitting in a room* (1969)

Alvin Lucier was born in New Hampshire, U.S., in 1931. In his early compositions, he incorporated the utilization of alpha waves to generate sub-sonic inaudible sound

[63] Pollio Vitruvius, Ibid. 77.

waves that made percussion instruments vibrate. His piece, *Music for solo performer*, represented his constant search for the roots, with an unstoppable desire to reveal the essence of life through music. In his own words:

> "[...] it's just an extension of what you do when you're a child at the beach and you put a shell up to your ear and hear the ocean. Then you stop. You don't do that as you grow older. Your ears stop doing that because you've got to think about other things, how to make a living and how speak to people, how to communicate verbally. I guess I'm trying to help people hold shells up to their ears and listen to the ocean again."[64]

Brandon Labelle describes Lucier's work as an explorative pursuit of how sound works as physical phenomena "[...] In his experimental compositions; Lucier explores auditory perception from a scientific point of view. Much of his work is influenced by the physical properties of sound itself."[65]

The properties of sound that Lucier helps explore in his works are always intended to appear in their most pure form where any type of sound manipulation gets in the way. His style could be defined as a search for the complexities within sound itself revealed through the apparently simplest and most unobtrusive compositional processes.

In the late 1960's Lucier pioneered the utilization of acoustical space as a compositional device. The two works chosen for this section of the study characterize his fascination with acoustical space and its musical implications.

In his piece *Chambers*, the first performance direction from the score reads: "Collect or make large and small resonant environments". [66] Those environments are detailed immediately afterwards and span from seashells to bays, tombs and canyons.

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[64] Alvin Lucier, Douglas Simon, *"Chambers",* (1980), 19.

[65] Seth Kim-Cohen, *"In the blink of an ear",* (2009), 193.

[66] Alvin Lucier, Douglas Simon, Ibid. 3.

Curiously, those items selected for the performance are classified as “environments”, not just resonating things or vibrating bodies, environments with their own acoustical properties that become exposed during the performance of the piece. His main idea was to move sound environments of different sizes into other environments, to carry sounds from one place to another, changing them.[67] Those sounds are grafted into foreign environments that operate as filters, with their own standing waves and resonating properties that re-model the qualities of the original sound source.

> In his own words: “When I was asked to write a score of *Chambers* for publication I decided to expand it. I wanted to make it bigger in the sense that it would imply more, so I extended it to include any resonant environment, large or small, that performers could use to produce or alter sounds in the same way that this room we're in alter our sounds. If a room can intrude its personality on whatever sounds occur in that room, then, any other size environment can do the same thing, so for the sake of performing I decided that performers could collect resonant objects into which they could put sounds, and the acoustic characteristics of the object themselves - shells, pots, pans and so forth - would alter the sounds with their own characteristics.”[68]

In this way Lucier forces the listener to create new links between the space suggested in the sound source and the environment in which it is actually being performed. Is that the sound of an orchestra coming from a bottle? Are the sound and shape of an object related? Why does this room sound as if it was bigger? Lucier’s compositions become complete only with the active participation of the listener establishing connections, imagining new sonic spaces, and being inquisitive about what is been proposed in the artwork. The listener is constantly challenged with incomplete sonic puzzles.

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[67] Geoff Smith and Nicola Walker Smith, “*New Voices: American Composers Talk About Their Music”,* (1995), 169.

[68] Alvin Lucier, Douglas Simon, Ibid. 10.

“A Beethoven symphony implies a large space, as the orchestra has a hundred players. If the symphony is recorded in a big hall, and the recording played from a two-inch loudspeaker, it's very strange, when you think about it. On the other hand, to try to recreate an environment and put it into another is like taking something that belongs somewhere and putting it somewhere else, so you make connections between things that wouldn't ordinarily make […] Some of art is that you make connections between things that no one else would ever make.”[69]

Lucier’s intentions always remain in their most pure form. His works offer ways to rediscover the roots of music, sound and its properties. In order to achieve that, he keeps an intransigent passive position towards sound manipulation. His desire is just to let the natural properties of sound sources emerge through these environments that modify them. Lucier’s position is not to artificially create “tuned” spaces that would reinforce certain acoustical properties. He is not interested in pursuing that line of thought; he just wants to find out what those environments “do” to sounds. Made environments would not fulfill that desire. That is why *Chambers* is performed using “found” environments[70] that make of each performance a singular learning experience.

“The performance environment element in *Chambers* remains unobtrusive; you can do almost anything in a performance of this piece as long as you think of it in terms of physical environments that alter sounds because of what they are.”[71]

The paradigm of *I am sitting in a room* is slightly different. Here Lucier’s goal is to let the acoustical properties of a room, a human-habitable enclosed space, surface

[69] Ibid. 13.

[70] Ibid. 12.

[71] Ibid. 11.

through the composition. The performance of the work is very simple; several sentences of recorded speech are continuously played back into a room and re-recorded there many times. As the repetitive process continues, those sounds common to the original spoken statement and those implied by the structural dimensions of the room are reinforced, being the other ones gradually eliminated. The space acts as a filter; the speech is transformed into pure sound. “Sound is always affected by the physical space in which it is heard. The size and shape of the room, the materials of the walls, floor and ceiling, the presence or absence of curtains and carpeting - all exert an influence. Some frequencies fit naturally in a given room and are therefore maintained with minimal degradation. Other frequencies, however, clash with the room and are canceled out.”[72]

The score of *I am sitting in a room* reads: “Choose a room the musical qualities of which you would like to evoke".[73] The instrumentation is the room, the resonant body is the room itself; the speech is a mere device that stimulates the acoustical properties of the chosen space. This initial statement describes the essence of the work, which is about evoking the musical qualities of enclosed spaces. When Barry Blesser makes the distinction between the proto-instruments and the meta-instruments[74], he is referring to the incompleteness of a musical instrument as a mere vibrating source. The direct vibration produced by the instrument (of any type) - the proto-instrument - is completed with the reflected vibrations provided by the space in which that sound is performed - the meta-instrument. The space of a concert hall is not simply a place for musicians and listeners to gather, but also an extension of the musical instruments played within it.

[72] Seth Kim-Cohen, Ibid. 186.

[73] Alvin Lucier, Douglas Simon, Ibid. 33.

[74] Barry Blesser and Linda Ruth Salter (2007), *“Spaces speak, are you listening?”,* 135 – 136.

A musical instrument has two acoustically bound elements: a source of energy (vibration) and a passive element (resonance that provides a particular timbral color). Those concepts are inseparably bound, as we cannot have in an enclosed space only direct sound or just reflected sound waves.

In *I am sitting in a room* the process leads to the unfolding of the most pure version of the meta-instrument. Every iteration during the performance of the work represents a deeper look at the resonances provided by the space that simultaneously obliterate the clarity of the speech. Through the process, the text becomes gradually incomprehensible, arriving at its climactic point when the speech goes from intelligibility to unintelligibility, or from words to music.[75] "Tunes seem to start letting the hidden melody of the room become audible."[76] The rooms then, have their own unique tunes that emerge through the process. That process is now the musical composition, music and process are inseparably bound in a new compositional model. "Rooms are musical instruments, with their physical dimensions and acoustical characteristics […] every musical instrument has its own particular wavelength; the higher the pitch, the shorter the wavelength. Actually, there's no such thing as "high" notes or "low" notes, we simply borrowed those terms from the visual world […]."[77] Following this path, we can say that Lucier's music is mainly based on the structural properties of sound itself; sounds are conceived as measurable wavelengths (instead of high or low musical notes) subverting the idea of music as a metaphor into a calculable fact connected to architecture.[78]

[75] Ibid. 39.

[76] Ibid. 37.

[77] Ibid. 35.

[78] Ibid. 36.

The work also makes evident the always-encroaching semantic decay of speech. The voice is always fading away. “In *I am sitting in a room*, it plays a cruel game with the listener, repeating itself [speech] for semantic confirmation, while at the same time eroding the sonic clarity that makes meaning possible.”[79]

The artistic value of this work is unquestionable and resides in Lucier’s deliberate intention to expose the gradual disintegration of the speech. An acoustical engineer would have arrived at the same result in one step but Lucier was reluctant to this, he was interested in the step-by-step process, in the progressive dissolution of the words and the reinforcement of the resonant frequencies of a room, in the gradual transformation of sound from pure energy to pure resonance.[80]

Iannis Xenakis - *Metastasis* (1954), the *Philips Pavilion* (1958) and Other Works

His dual expertise as a composer and a professional architect make Iannis Xenakis one of the paradigmatic contemporary music figures of the second half of the 20th c.

Ianniks Xenakis was born in 1922, of Greek parents in Braila, Rumania, on the Danube. His early musical studies were mainly with Aristotle Kundurov, pupil of Ippolitov-Ivanov. At that time he was particularly interested in Greek traditional music - that of the Byzantine Church and folk music; and this inspired him to write some choral and instrumental works, which he later destroyed. But already in this modal music he had begun his explorations in timbre and sonority. Along with his musical studies Xenakis pursued a scientific education that took him to the Polytechnic School in Athens

[79] Seth Kim-Cohen, Ibid. 191.

[80] Alvin Lucier, Douglas Simon, Ibid. 34.

from which he graduated in 1947 with an engineering degree that opened the door to him for a brilliant career as an architect.[81]

The same year, he left Athens for Paris where he continued his musical studies under Arthur Honegger and Darius Milhaud. He attended Olivier Messiaen's courses in analysis and musical aesthetics at the Paris Conservatoire.[82]

Also in 1947, Xenakis was able to get a job at Le Corbusier's architectural studio. He worked as an engineering assistant at first, but quickly rose to performing more important tasks, and eventually to collaborating with Le Corbusier on major projects. The most significant was the *Philips Pavilion at Expo 58,* despite the fact that it was actually completed by Xenakis himself, using a basic sketch by Le Corbusier.[83]

The experience Xenakis gained at Le Corbusier's studio played a major role in his music: important early compositions such as *Metastasis* and *Le Sacrifice* were based directly on architectural concepts. In the latter, he experimented with numerical proportions in the same way Le Corbusier had done*,* following a quite logical step in his line of thought, probably incentivized by the numerous references to music contained in *Le Modulor.*

Despite the fact that he never conceptualized theoretically his way of linking music and architecture, Xenakis treated both arts from a scientific and mathematical perspective. His *Formalized Music* (1971) is a perfect example of his desire to apply

[81] Mario Bois, *"Iannis Xenakis, The man and his music. A conversation with the composer and a description of his works",* (1980), 3.

[82] Ibid. 3.

[83] Ibid. 3 – 4.

mathematical “control” to every single parameter of music composition. As he expressed it: “Every sonic event may be expressed as a vectorial multiplicity.”[84]

Xenakis’ early period reflects his utmost rigor towards music composition as a purely logical activity, therefore relevant for this section of the study. Every sonic event was the convergence of vectors taken from matrixes based on probabilities and proportions. The application of these vectors was strict, sometimes compromising the ultimate artistic result. In *Le Sacrifice* (1953), for example, this rigid algorithmic approach was not really successful, as the simple permutation of two sets of values was excessively simple to keep the listener’s attention.[85]

Whereas in *Zyia* (1952), Xenakis draws freely on elements derived from traditional Greek practice, in *Le Sacrifice* he constructs an edifice worthy of the European avant-garde of the 1950s:

> “In the manner of Messiaen's "modal" serialism, Xenakis bases his composition on a series of eight pitches fixed in register, each linked to a duration derived from the Fibonacci series. These pitches are elaborated by neighboring notes and glissandi in between, characteristic features of later pieces [...] The deployment and repetition of the associated durations follows a mathematical process [...] The work is an orchestral piece constructed on the basis of a melodic series of eight pitches, associated with a scale of 8 durations whose values (in 16th notes) were determined by the first 8 numbers of the Fibonacci series.”[86]

However, one year later, “in *Metastasis*, Xenakis leaves no trace of how he views the relationship between the abstract serial structure of *Le Sacrifice* and his original inspiration from the Dionysian sacrifice of the bulls. That the text had been dropped

[84] Ianniks Xenakis, Ibid. 162.

[85] Sven Sterken, *“Music as an Art of Space: Interactions between Music and Architecture in the Work of Iannis Xenakis.”* From *“Resonance. Essays on the intersection of Music and Architecture”* (2007) Mikesch W. Muecke and Miriam S. Zach, editors. 24.

[86] Ibid. 24.

from the music is certainly of some significance.”[87] According to Harley, it is possible to hypothesize that Xenakis could only find a true expression of the ritual through an absolute abstraction.[88]

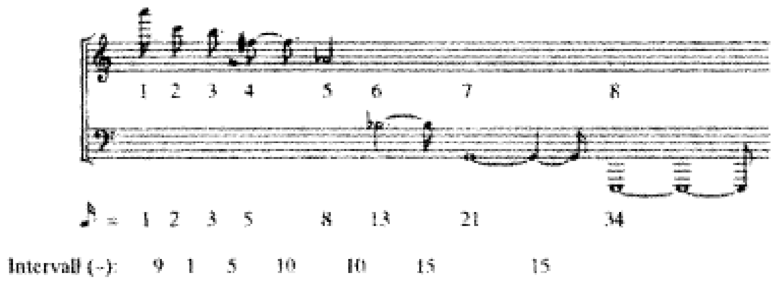

Figure 2-14. Iannis Xenakis, *Le Sacrifice* (1953). Source: Andre Baltensperger, Iannis Xenakis und die Stochastische Musik. Komposition im Spannungsfeld von Architektur und Mathematik (Bern: Haupt Verlag, 1996): 231.

In Xenakis’ proposed processes, the composer decides on the elements that complete the sets of values, their algebraic relations and how they influence the vectors that are ultimately translated into musical terms. Music becomes organization that he defines as “an organization of elementary operations and relations between sonic entities or between functions of sonic entities.”[89] This new approach to music composition obliterates the existence of musical material that is not under total control by the composer. The ideas of improvisation - where the performer is at the same level in the creative process as the composer - and indeterminacy, were inadmissible for Xenakis at the time. From his point of view, the composer is a self-sufficient builder who decides on every aspect of the composition until the utmost detail, determining foundations, dimensions, materials and design. However, he does not believe that the

[87] James Harley, *“Xenakis: his life in music”* (2004), 5 – 6.

[88] Ibid. 5 – 6.

[89] Ianniks Xenakis, *“Formalized music”* (1971), 4.

performer's role is by any means related to the completion of the work as all decisions are fully calculated by the composer. The performer gets in some way relegated to a less relevant function, as a mere operator with very little room to make creative decisions. Xenakis' eventual transition to computer music (later in his career) is the natural consequence of this implacable desire for total control. "To make music is nothing but to express human intelligence by sonic means. This intelligence is conceived in its broadest sense, which includes not only the peregrinations of pure logic but also the 'logic' of emotions and intuition. […] In the end, a musical composition offers a collection of logical sequences, which it wishes to be casual." [90]

After various unfruitful attempts to find a mentor, Xenakis was finally accepted in Oliver Messiaen's composition class with whom he studied between 1951–53. Messiaen immediately recognized Xenakis's talent:

> "I understood straight away that he was not someone like the others. [...] He is of superior intelligence. [...] I did something horrible, which I should do with no other student, for I think one should study harmony and counterpoint. But this was a man so much out of the ordinary that I said... No, you are almost thirty, you have the good fortune of being Greek, of being an architect and having studied special mathematics. Take advantage of these things. Do them in your music." [91]

Messiaen and his students studied music from a wide range of genres and styles, with particular attention to rhythm. Messiaen gave Xenakis some key advice, suggesting him to incorporate in his pieces the two central elements of his then daily routine, that is to say the *Modulor* and the use of graph paper. He applied the *Modulor* to systematize

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[90] Ibid. 178.

[91] Sven Sterken, Ibid. 23.

the logical proportions and the graph paper in order to determine pitch content, densities and structure.[92]

Figure 2-15. Iannis Xenakis, *Metastasis* (1954) measures 309 – 314.

[92] Jean Boivin, *"La Classe de Messiaen".* (1995). Paris: Christian Bourgois.

A clear example of Xenakis' application of his daily tools can be seen on his translation of the first bars of *Matastasis* from the graph paper into traditional music notation. The scientific thought addressed in the design of the hyperbolic paraboloids can be clearly seen in the orthogonality of the score. Every sonic event is considered as a sum of vectors. The *x* and *y* coordinates in this case represent pitch and time respectively, being the continuous linear *glissandi* in the strings, which creates the volume of the figure (as they actually do in the graph paper). The aural illusion resides on the fact that those massive straight lines of sound create curves that move in a three dimensional sonic space.

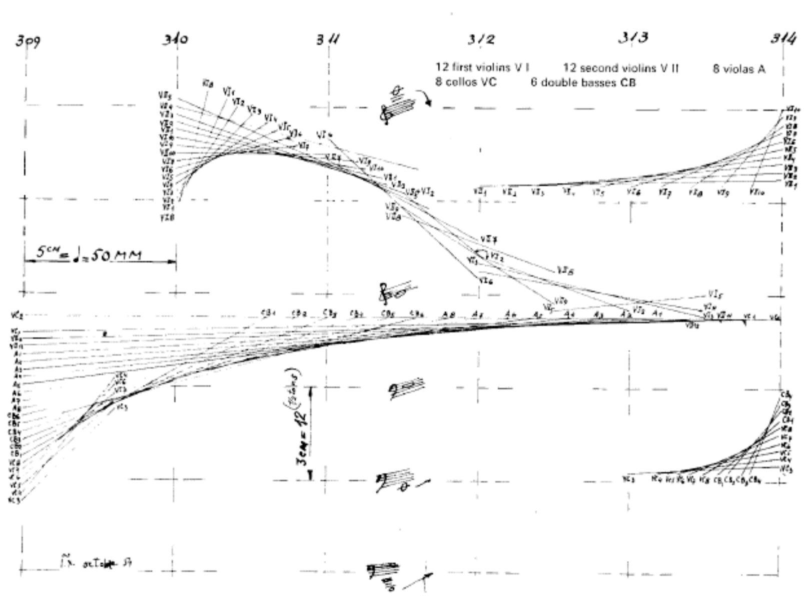

Figure 2-16. Excerpt of the graph paper design of the string glissandi in *Metastasis* measures 309-314.

He also arrived to new architectural solutions that were influenced by his previous musical research. *Metastasis*, which was a purely musical work, had pointed towards certain approaches in architecture by means of which, later in 1956, he was able to design the *Phillips Pavilion* for the *Brussels* exhibition. The music of *Metastasis*, from 1953, commanded the ideas for this project.[93]

"If *glissandi* are long and sufficiently interlaced, we obtain sonic spaces of continuous evolution. It is possible to produce ruled surfaces by drawing the *glissandi* as straight lines."[94] Parameters of speed rate, the distance (register) covered by the *glissandi* and dynamics are carefully calculated using stochastics. According to Xenakis, the data appears to be aleatory only at the first hearing. Afterwards, and during re-hearings, the relations between the events predetermined by stochastics, start to take on a definite meaning to the listener, initiating a special logical cohesion capable of satisfying the listener's intellect and aesthetic sense. In Xenakis own words: "The sonic scheme defined under this form of vector-matrix is consequently capable of establishing a more or less self-determined regulation of the rare sonic events contained in a musical composition sample. It represents a compositional attitude, a fundamentally stochastic behavior, a unity of superior order".[95] The utilization of lines as a basic compositional tool in Xenakis is similar to what Daniel Libeskind manifests – now in the realm of architectural design – through his works. Libeskind shows a deep interest in the profound relation, which exists "between the intuition of geometric structure as it manifests itself in a pre-objective sphere of experience."[96] The materialization of those "ideal" geometric structures and their formalization are not necessarily connected. Libeskind's and Xenakis's creative processes start almost identically, both begin with

[93] Mario Bois, Ibid. 5.

[94] Ianniks Xenakis, Ibid. 10.

[95] Ibid. 37.

[96] Daniel Libeskind, *"Countersign"* (1991), 14.

orthogonal planes where simple lines become complex multidimensional figures. In Xenakis, the materialization is through sound, in Libeskind through a building. This difference gets blurred if we compare the graphical origins of the *Philips Pavilion* (based on Xenakis' musical experiments in *Metastasis*) and Libeskind's conception of his first materialized project, the *Jewish Museum in Berlin.* Libeskind himself has entitled the project "*between the lines"*, implying that it is in this intermediate zone (when a design is completed but not materialized) where the essential lies. The design of the museum is a project about two lines of thinking, organization and relationship. "One is a straight line, but broken into many fragments; the other is a tortuous line but continuing indefinitely. These two lines develop architecturally and programmatically through a limited but definite dialogue. They also fall apart, become disengaged, and are seen as separated."[97]

In architecture, lines define the relationship between material and immaterial reality. Any two lines on the paper of an architectural plan will shape and delimit the empty space between them, and at the same time configure the solid, impenetrable masses of the projected structure.[98] Lines that separate, lines that intersect and become vectors, lines in graph paper, various densities of lines, thick and thin, curved and straight, Xenakis and Libeskind never abandoned the recurrence to the pillars of architecture in their work.

Xenakis' probabilistic studies annihilate any possibility of "chance" in his works. Purely aleatoric events seem to be – in Xenakis' viewpoint – a truly simplistic activity,

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[97] Ibid. 86.

[98] Bernhard Schneider, *"Daniel Libeskind: Jewish Museum Berlin"* (1999), 36.

worthless to a musician. Consequently, "the calculation of the aleatory, that is to say stochastics, guarantees first that in a region of precise definition slips will not be made, and then furnishes a powerful method of reasoning and enrichment of the sonic processes."[99] In this sonic environment, the listener is required to participate intelligently in the musical discourse in order to establish its definite meaning.

Several of Xenakis' works - including *Metastasis* - have an undeniable graphical origin. Some of them as sets of coordinates in the orthogonal plane and others - like *Terretektorh* (1965) - as a sketch for the spatial organization of the sound sources.

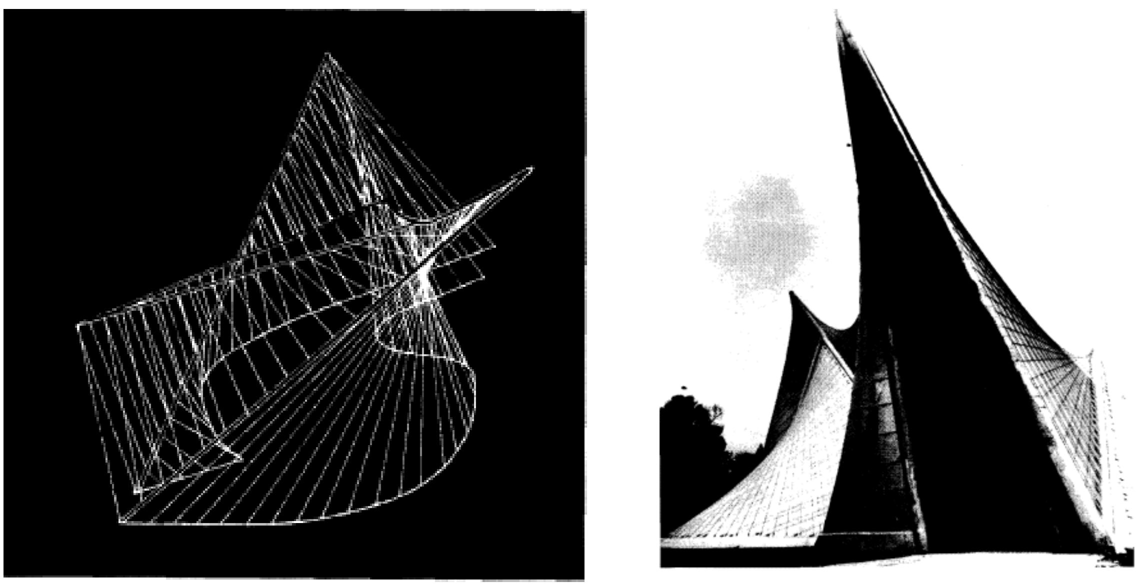

Figure 2-17. Images of the first model (left) of the *Philips Pavilion* and its finalized version (right) at the *Brussels World's fair*, 1958.

More so, his experiments from *Metastasis* were a direct influence in the design of the *Philips Pavilion* in 1958. Those works were constructions based on hyperbolic

[99] Ianniks Xenakis, Ibid. 39.

paraboloids, the first being in the sound domain and the latter in the realm of architecture.

A straight line in a two dimensional space represents the continuous change of one dimension compared to the other. The same happens between the pitch and time domains, the straight line is the continuous change of pitch versus time. Therefore, musical space is homogeneous as its two dimensions are lengths and distances. Despite that fact, these two musical dimensions are alien in nature from one another and are connected only by their ordering structure.[100] Xenakis conceived those structures independently in what he called organizations in time and outside time.[101]

Paradoxically, Xenakis was conceptually unsympathetic to the use of graphic notation. He sustained that the *"*graphists*"* exalted the value of the symbol above the sound of the music, which is valued according to the quality of the drawings and not to the intrinsic beauty of the sound. Absolute control and planning are architectural principles that are evident in Xenakis' creative processes. In his reasoning, the score – similar to the architectural plan – is constituted by a detailed set of instructions for the performer-builder. Through his meticulousness, Xenakis intends to think like a painter who can deal directly with the existent reality of his own work, without this indirect and imprecise "translation stage" by the performer. "Even scores that may appear similar may actually be extremely different in their notational function as different notational systems can use the same symbols in much the same way that different languages can

[100] Balint Andras Varga, *"Conversations with Iannis Xenakis"* (1996), 70.

[101] Iannis Xenakis, Ibid. 193.

use some of the same letters in their alphabets"[102]. Performers can also interpret those symbols differently, which emphasizes the clash with Xenakis' desire to control everything through his scores. Not by chance, his approach to aleatoric and chance music was analogous: "[…] the so-called aleatoric music, which is an abuse of language […]. This group is ignorant of the fact that graphical writing, whether it be symbolic, as in traditional notation, geometric, or numerical, should be no more than an image that is as faithful as possible to all the instructions the composer gives to the orchestra or to the machine."[103] Graphic notation is essentially an incomplete set of instructions that delegate compositional responsibility to the performer, open in essence, undetermined but with an identity, therefore recognizable. In this regard, Earle Brown's approach is Xenakis' opposite, as he accepts flexibility and indeterminacy: "There must be a fixed (even flexible) sound content, to establish the character of the work, in order to be called 'open' or 'available' form. We recognize people regardless of what they are doing or saying or how they are dressed if their basic identity has been established as a constant but flexible function of being alive."[104]

Even still, Xenakis admitted the use of graphical notation for the sake of continuity between musical thought and its visual representation. The immediate mapping of a sonic ramification in the Cartesian system provides an exact picture of the sound or "what it sounds like", something inconceivable when utilizing traditional musical

[102] Theresa Sauer, Ibid. P 11, excerpt from *"An introduction to the Scribing Sounds Exhibit"* by Sylvia Smith.

[103] Ianniks Xenakis, Ibid. 180.

[104] Theresa Sauer, Ibid. 10, from Earle Brown and Ryan David, on Brown's available forms 1. "*Contemporary Music Making for Amateurs" (CoMA)* 2006.

notation.[105] “It is well known that notation has been a constant difficulty and frustration to composers, being a relatively inefficient and incomplete transcription of the infinite totality of what a composer traditionally "hears" […].”[106] Xenakis and Brown seem to agree on the "vitality" provided by the graphic notation and about the immediacy that it provides between composer and sound represented on paper. Even though, their main conceptual difference resides on the fact that graphic notation was, for Xenakis, just an initial practical step in his process that required further translation, for Brown, instead, it represented a self-sufficient musical score. The last step in Xenakis’ compositional process is the translation into traditional notation, which explains the complexity of his scores. His creative process starts by establishing an overall view of the work, and afterwards by choosing the materials and how they relate to each other, conjointly or independently, until they become organized. In this way his work resembles that of an architect, or more correctly of a sculptor. “[…] a musical thing must be a living organism, it must have a head and arms; it would be better to speak of biology than architecture. In music, space is not three-dimensional, it is multi-dimensional.” [107]

Despite the fact that Xenakis never wrote a piece with acoustical space in mind, he composed the *Concrèt PH* (for electronic media) specifically for the *Phillips Pavilion*. The work was based on manipulations of the sound of burning charcoal and played through the 350 speakers located according to Edgard Varese’s spatialization plan. However, the main composition for the installation was *Poeme Electronique* by Varese

[105] Balint Andras Varga, Ibid. 90.

[106] Theresa Sauer, *“Notations 21”* (2009), 40.

[107] Mario Bois, Ibid. 13.

who drew up a detailed spatialization scheme for the entire piece, which made great use of the physical layout of the pavilion.

In a similar scenario, the composer Steve Roden took a radically different approach. In his *Pavilion Score* (2005), the composer was asked to create a sound work related to an architectural structure. The building was also a pavilion, the *Serpentine Gallery's Summer Pavilion* designed by Alvaro Siza, Eduardo Souto de Mora and Cecil Balmond. Despite that initial similarity, the fundamentally opposed approach taken by the composer is here remarkable. In this case Roden's process was relatively simple: eight different colored pencils (one for each note on an already color-coded child's glockenspiel) where used to fill in the pavilion plans with colors indicating musical notes. “The intention was that these scores would be playable by anyone - musician or not, mapping the space in sound so the audience could listen to a drawing in sound of the space in which they were located.”[108]

Xenakis also suggested a novel approach to space or spatialization of sound sources without electronic means in his work *Terrekektorh,* were musicians are sprinkled around the audience, with the conductor at the centre on a circular podium. His desire was to place the orchestra among the audience in order to regain the 50% of the sound that usually gets lost when listening from the distance (as in a theatre), and to “drown the listener with sound, as in a storm or rain.”[109] This new idea also embedded inevitable unique experiences by the listener depending on his location within the performing forces. An audience member sitting next to the trombone would necessarily

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[108] Theresa Sauer, Ibid. 193.

[109] Mario Boise, Ibid. 20.

have a radically different experience of the work from the one located near one of the violins. This new vision of the orchestra as a malleable sound source does not reveal a limited confidence in pure music - on the contrary - it expands its sonic horizons for the listener, the performer and the composer.[110]

In *Metastasis*, Xenakis also resorted to numerical proportions to determine the temporal structures. The section starting at measure 104 shows his new conception of the rhythmic microstructures. The section is marked quarter note = 50 which operates as the temporal unit for all (initial) 6 voices, facilitating its performance. These tiny rhythmical structures are essentially poly-metrical as a result of the different grades of density of the individual lines. There is not a polyphonic thought in this section; the intricate texture is the natural consequence of the application of a matrix of densities similar to the ones he developed in *Formalized Music*.

In order to understand this process we first have to build a matrix reflecting all the values we want to control in the composition. In this case, we have an initial “density matrix” that works as a model.

Table 2-1. Rhythmic density ratios as proposed by Xenakis in *Formalized Music*.

Event	Density λ =	
	Sounds/measure 26 MM	Sounds/sec
zero	0	0
single	5	2.2
double	10	4.4
triple	15	6.6
quadruple	20	8.8

110 Ianniks Xenakis, Ibid. 181.

“We must specify the unit-events, whose frequencies were adjusted in the standard matrix. We shall take as a single event a “cloud” of sounds with a linear density λ sounds/second. 10 sounds/second is about the limit that a normal orchestra can play. We shall choose $\lambda = 5$ sounds/measure at MM 26, so that $\lambda = 2.2$ sounds/sec.”[111]

The specific tempo markings in m. 104 of *Metastasis* (MM = 50) as well as the poly-metrical rhythmic structure (4/16, 3/8 and 5/16) slightly change the values of the matrix keeping the fundamental concept unaltered. That measure unit change (from MM = 26 to MM = 50) also has a practical consequence as it facilitates the work of the performers and the conductor. The composer does not resign any of his textural desires; he just absorbs through the notation all the unnecessary difficulties. Here Xenakis translates the original matrix, which becomes a sonically complex musical score that is relatively easy to perform. The musician - in this section of the work - only needs to keep an invariable subdivision in order to fulfill the role sought by the composer. “I do take into account the physical limitations of the performers, otherwise I would have written symphonic compositions for a single interpreter, for one piano. But I also take into account the fact that what is a limitation today may not be so tomorrow.”[112]

In the following matrix (with the specific data from the studied section from *Metastasis)* the sounds/measure is similar to the sounds/second. Xenakis – presumably for practical reasons – chose the rate of sound events/unit (measure).

[111] Ibid. 32.

[112] Balint Andras Varga, Ibid. 65.

Table 2-2. Rhythmic density ratios in m. 96 - 116 from *Metastasis.*

Event	Density λ =	
	Sounds/measure 50 MM	Sounds/sec
zero	0	0
single	5	4.16
double	10	12

In this section of the work the 10 notes per measure are achieved as a result of the mathematical relation between the chosen meters; 3/8, 4/16 and 5/16 have the same measure unit (MM 50) which is divided by each meter in unequal parts, resulting - if all the subdivisions are played - in 10 consecutive attacks (as marked in figure 2-20). The only simultaneity would happen at the beginning of each unit (measure) but Xenakis chooses to hide that element of synchronicity between the meters in order to keep the pulse unrevealed and the listener engaged with the varying sonic densities. These densities are controlled by the quantity of unit subdivisions performed by each instrument. From the following excerpt we can appreciate that m. 106 has a density of 5 events/unit and m. 108 of 7 events/unit. Later on, in m. 144 – 145 the curve of rhythmic densities reaches its peak in two consecutive units (measures) with a density ratio of 10 events /unit.

Figure 2-18. Measures 94 – 116 from *Metastasis.*

The rhythmic structure in m. 104 of *Metastasis* is based on those calculations that are based on stochastic results where rhythm is not just a succession of events in time but the amount of sound events that occur during a fixed (length unit) period of time. This parallel between rhythm an density comes from Xenakis' architectural experiments in his design for the *Monastery of La Tourette* (1953-56) where he applied width progressions based on *Le Modulor*.[113] In this example from *Metastasis*, Xenakis combined his own matrix, to control the micro-rhythm-structures, with Le Corbusier's proportions, to manage their utilization in the overall macro-form of the composition.

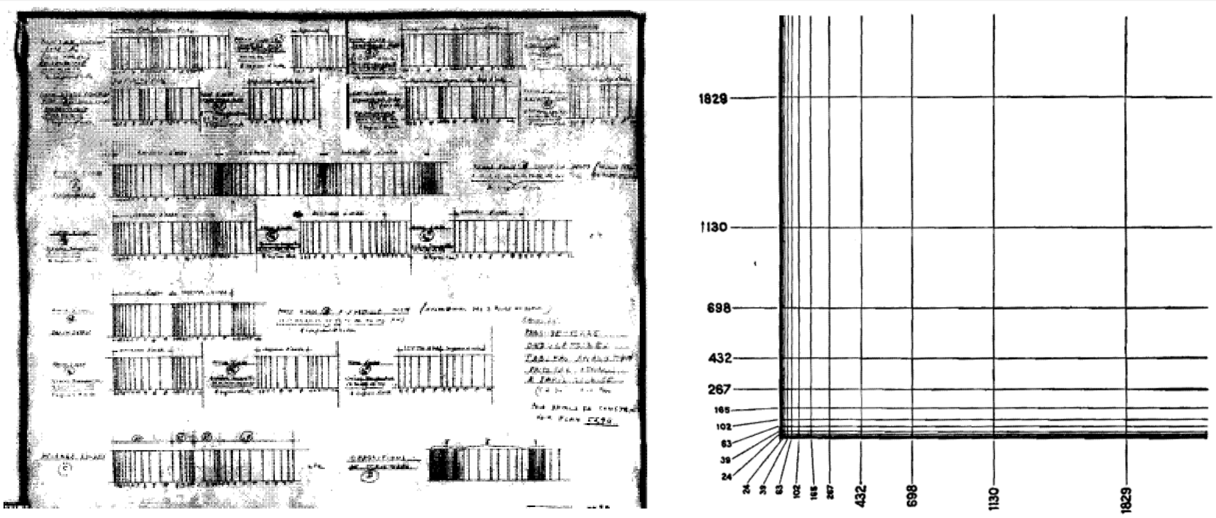

Figure 2-19. (left) Table with progressions of rectangles with increasing widths drawn from *Le Modulor*. The preliminary ideas for the *Monastery of La Tourette*. (right) table of proportions from *Le Modulor* that govern Xenakis' concept of density – both is musical rhythm and architectural design.

This massively active texture of overlapped parts (in *divisi*) that move at different rates is not only the result of Xenakis' compositional processes but also a natural consequence of his aesthetic vision towards polyphonic composition. He thought that linear polyphony was self-destructive in its complexity, and it prevented the listener from

113 Sven Sterken, Ibid. 21 – 44.

following the tangled lines. According to Xenakis “its [polyphonic composition] effect is one of unreasonable and gratuitous dispersion of sounds over the whole sound spectrum”. [114] From his viewpoint, there is a contradiction between the linear polyphonic system and its audible result, which ends up being a surface, a mass. In order to avoid this inherent contradiction of polyphony, sounds need to become totally independent, forming a texture in which the linear combinations and their polyphonic superposition are no longer workable. “In such environment, what matters is the statistical average of isolated states of the components’ transformations at any given moment.”[115] That is Xenakis' justification of the use of calculations in order to control the evolution of each of the components in textures that are not the result of interwoven individual lines (like in polyphony) but sound-masses, vast groups of sound events governed by the principles of density, degree of order, and rate of change, which require definitions and realizations using probability theory.

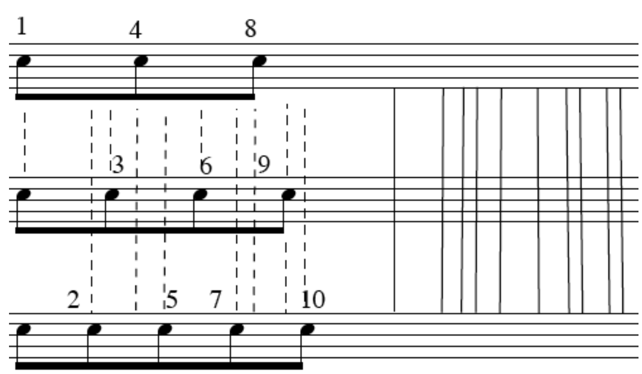

Figure 2-20. The poly-metrical section from m.104 from *Metastasis* and a graphical representation of its rhythmical density, which recalls the design and table of the *Monastery of La Tourette*.

[114] Ianniks Xenakis, Ibid. 182.

[115] Ibid. 182.

In Xenakis' aesthetic, specifically in his early works, the connection between music and architecture has less to do with common features than with the existence of a third element that acts as an intermediate between both fields: mathematical proportions in the first case and the concept of space in the second.[116]

Despite the fact that he never articulated theoretically his way of linking music and architecture, Xenakis treated both arts from a scientific and mathematical perspective. *Formalized Music* (1971) is a perfect example of his desire to apply mathematical "control" to every single parameter of music composition. As he expressed it: "Every sonic event may be expressed as a vectorial multiplicity."[117]

If we consider ordered sets *H* (pitches in Hz), *G* (intensity intervals in dB), *U* (time intervals in seconds) and *T* (amount of space between sonic events in seconds), we could define the next event as: H = 440, G = 60, U = 4, T = 0.

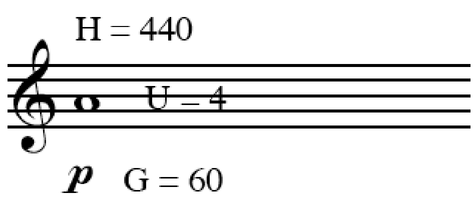

Figure 2-21. Musical note as a vectorial multiplicity.

Those values, however, do not come from any acoustical consideration of an enclosed space and are not related whatsoever with architectural acoustics. Xenakis did not consider space as a component of his matrixes nor had the desire to use the aural and measurable properties of rooms as the basis for his compositions.

[116] Sven Sterken, Ibid. 22.

[117] Ianniks Xenakis, Ibid. 162.

In the preface to the book, Xenakis also expresses a profound need to understand and explain sonic events through a formal process. Understanding, logic, scientific thought, reasoned support, and human intelligence are key words in this section that also summarize Xenakis' aesthetic vision. The following passage is the milestone of his early works, in which he justifies his need of a prior control and logical understanding of every musical parameter employed in a composition. His scientific thought unavoidably re-conceptualized music as a product of human intelligence.

> "The effort to reduce certain sound sensations, to understand their logical causes, to dominate them, and then to use them in wanted constructions; the effort to materialize movements of thought through sounds, then to test them in compositions; the effort to understand better the pieces of the past by searching for an underlying unit which would be identical with that of the scientific thought of our time; the effort to make "art" while "geometrizing", that is, by giving it a reasoned support less perishable than the impulse of the moment, and hence more serious, more worthy of the fierce fight which the human intelligence wages in all other domains - all these efforts have led to a sort of abstraction and formalization of the musical compositional act."[118]

"The constant rational questing in the arts is imperishable, it lies latent or it dominates according to the *epoch*, is always there."[119] In Xenakis' musical world, compositions are reifications and formal structures of abstract ideas - not ends - that are later incorporated into families of compositions.

Daniel Libeskind – *The Jewish Museum of Berlin* (1999) and Aesthetic Considerations on Other Works

Daniel Libeskind (b. Poland 1946) is one of the most prominent names in 21st c. architectural practice and urban design. Libeskind is also well known for introducing a new critical discourse into architecture and for his multidisciplinary approach. His

[118] Ibid. Preface 9.

[119] Mario Bois, Ibid. 10.

practice extends from building major cultural institutions (including museums and concert halls, landscape and urban projects), to stage design (installations and exhibitions). Unlike Xenakis', Libeskind's artistic direction was, ultimately, in the realm of architecture. However, his background as a music performer is always present in his approach towards architecture, which he conceives as an abstract form of art absolutely alienated from its materialization. He studied music in Israel on the America-Israel Cultural Foundation Scholarship and later in New York where he was recognized as a virtuoso piano performer.[120] He eventually left his music studies to focus exclusively on the study of architecture, obtaining his architectural degree at the Cooper Union for the Advancement of Science and Art in 1970. In 1990, Libeskind was awarded the first prize in the competition for the Berlin Museum with the *Jewish Museum* project, which in 1999 became his first materialized (built) architectural design.[121]

From Libeskind's viewpoint, architecture does not necessarily depend on the activity of "building" to exist. Architecture "is" the plan, architecture "is" the architect's drawing on paper. His drawings and collages from *Chamber Works* "develop an area of architectural thinking, which is neither physics nor poetics of space, where the ultimate reality of architecture is not its material becoming."[122] His architectural explorations in the series *Micromegas* and the *Three Lessons of Architecture* (*machines)* are studies that are not meant to do anything, they are just etudes that address specific architectural problems through creative works. The concepts of these pieces are still present in Libeskind's later works as recurrent ideas. Those "scores" - as he calls them -

[120] Bernhard Schneider, *"Daniel Libeskind: Jewish Museum Berlin"* (1999), 60.

[121] Ibid. 60.

[122] Daniel Libeskind, *"Countersign"* (1991), 15.

become the models for newer works[123] obliterating the difference between architectural theory and practice. He approaches architecture as a music composer, conceiving his architectural work a deep moment of introspection, a moment, as he calls it, "to work on yourself". [124] The ultimate work result, the "object", is naturally expected. The architect is then responsible for its production and, therefore, for part of its realization. Furthermore, making an architectural piece - like composing a piece of music - comprises all the people who are involved in the process, all those who are part in the building-composing trajectory, from its conception to its final result.[125]

His *Three Lessons of Architecture* and *Chamber Works* manifest a desire to challenge the traditional foundations of the discipline. Architecture is then, like music, an absolutely abstract art of pure space for limitless imagination or as he defines it: "Architecture - that divine luxury of faith, highest crystallization of the material liberty of humanity, its imagination and spirit […]". Also striving for an artistic identity through his discipline, he continues: "[architecture] must never succumb to being the degraded product of necessity provided by the technicians of educational and monetary utopias."[126] In less than fifty years, Le Corbusier (in *Le Modulor)* and Libeskind, attributed to architecture a totally opposed meaning: a model for mass production for the first, and anything but a model for mass production for the latter. Le Corbusier embedded his artistic identity within the model he created, not through the constructions that resulted after its implementation. On the contrary, Libeskind reflects his artistic

[123] Daniel Libeskind*, "Counterpoint: Daniel Libeskind. In conversation with Paul Goldberger"* (2008), 11.

[124] Fabio Oppici and Enrique Walker, *"12 Entrevistas con arquitectos"* (1998), 132.

[125] Ibid.132.

[126] Daniel Libeskind, *"Radix-matrix"* (1997), 155.

personality in the individuality of all of his works, which cannot be successfully transplanted nor even imagined in a different environment. His works intentionally capture the history and project it into the future. In his project *Musicon Bremen,* for the Philharmonic Hall in Bremen, Germany, Libeskind proposes a hall where musical performance is clearly the central goal of the building, which, at the same time, creates deep connections with the history of the city where it is located.

The visual queues are also present in the design, manifesting Libeskind's deep desire for assimilation. The new museum (*Jewish Museum in Berlin*) harmoniously integrates with the contiguous *Collegienhaus* and the other buildings of the surrounding area exhibiting a compelling spatial juxtaposition of key historical buildings and architectural styles. "A visitor can glimpse through the new construction and reestablish the link with familiar spatial relationships and architectural scales. On the other hand, those constructions also serve to underscore the unsettling and exciting divergence of the new building from the rule."[127] Thus, the new building gets integrated with the older surrounding constructions, in a sort of understanding of the past and its projections towards the future. The *Jewish Museum* does not negate the historical legacy of its surroundings; on the other hand, it integrates it and projects it hereafter. "This apparent clash is somehow unexplainable but at the same time unique, people of all ages, walks of life, and cultural backgrounds appear to experience the drama and emotional force of this extraordinary spatial configuration immediately and instinctively."[128]

[127] Bernhard Schneider, Ibid. 57.

[128] Ibid. 58.

Libeskind is part of a historical tradition in architecture whereby drawings (as well as other forms of communication) denote more than what can be embodied in frameworks of objective data (such as buildings). “If we can go beyond the material carrier [building] into the internal reality of the drawing, the reduction of the representation to a formal system […] begins to appear as an extension of the reality […]. The system ceases to be perceived as a prop whose coherence is supported by empty symbols, and reveals itself as a structure whose manifestation is only mediated in symbolism.”[129]

Like in Debussy, in Libeskind symbolism and functionality are intertwined. The *Jewish Museum* has several "voids" (negative spaces of utter silence that are arranged along an absolutely straight line through the entire structure).[130] Those spaces are "holes" of silence, where aural architecture evokes the devastation of the holocaust. About this, Libeskind says: “ […] unlike Wittgestein, who thought that where there is silence there is nothing more to say, I believe, on the contrary, that where there is silence there is most to be said. I've never believed in the silent space of architecture where the forms create the illusion that all has been said. I prefer buildings that don't anesthetize us but make us more alive.”[131]

The spiraled line of thought in Debussy was guided by his constant reinvention of his musical material through his works. His artistic identity continuously grows from the originality of his musical substance as well as from his endless processes of transformation. In Libeskind, the idea of identity through his work is similar, with a basis

[129] Daniel Libeskind, Ibid. 14.

[130] Bernhard Schneider, Ibid. 51.

[131] Daniel Libeskind*, “Counterpoint: Daniel Libeskind. In conversation with Paul Goldberger”* (2008), 16.

expressed in his early experiments (*Chamber Works, Three lessons in Architecture and Micromegas)* that is then “orchestrated” (built) responding to specific needs. The main concepts are always present and his desire to preserve freshness and individuality in his work stays untouched.

“The artistic originality is a need that always fights to overcome the demands of large amounts of work.”[132] For Libeskind, poets, writers, and composers face the same challenge that is to avoid becoming formulaic.[133] Each of his works is necessarily unique; each of his buildings is extremely specific regarding its location and does not suggest that it could be easily transported to another setting.[134]

In addition to the visual and aural components, the spatiality of a building has to be a part of the story it tries to communicate. According to Libeskind, an architectural plan is not just a container to be filled; it is part of the symbolism of the building. “That symbol transports the visitor [the listener in a music composition] beyond the material reality and, in architecture [or in music], towards the realm of what cannot be articulated through language.”[135]

Architectural acoustics are also important for Libeskind. His design proposal for the *Musicon Bremen* shows a deep concern about the aural properties of the design. Despite that fact, the *Musicon* is not exclusively designed for musical performance, which necessarily alters the approach of the designer into a more crossover idea: an acoustical design that fits several needs or so called “multipurpose”. “The care for

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[132] Daniel Libeskind, ibid. 8.

[133] Ibid. 8.

[134] Ibid. 9.

[135] Ibid. 14.

acoustics in a room is not only for a music hall but also for every building. Interestingly, our sense of balance and relationship to gravity and to the ground lies in our ears and not in our eyes. A well-balanced design devotes equal care to how a building looks like as well as how it sounds, if it enhances or becomes obtrusive of the sonic events that take place within it."[136]

"An architectural drawing is as much a prospective unfolding of future possibilities as it is a recovery of a particular history to whose intentions it testifies and whose limits it always challenges. In any case, a drawing is more than the shadow of an object, more than a pile of lines, more than a resignation to the inertia of convention."[137] That non-conventionality is what brings Libeskind's thinking even closer to music. Like Xenakis, his ground rules stay unaltered. Both artists start from the endless possibilities of the basic "simple lines" to evoke multidimensionality, space, volume, shape, density, and other converging concepts between music composition and architectural design. Again, it is interesting to see that an architectural design can potentially become a piece of music, like in *Metastasis*, or a building, like the *Jewish Museum* or the *Philips Pavilion*. The artistry of the architect is within the design itself, not in its materialization; which, as it was discussed before, is not exclusively in the realm of architecture. Taking these ideas to the extreme, if we say that architectural design exists even without a building, and we consider music to be "complete" without a performance, then the two disciplines are equal, and the composer and the architect have interchangeable roles. The music becomes such when it is composed and the architectural design when it is drawn.

[136] Daniel Libeskind, "*Countersign"* (1991).

[137] Ibid. 14.

Paradoxically, there is not a direct correlation at the moment of the materialization, as an architectural design could become sound and a musical score a building.

Libeskind, showing his multidisciplinary approach, blurs even more the apparent differences between the two disciplines as he says:

> "I see architecture as musical. When I look at buildings, I don't just see them as planes, two-dimensional or three-dimensional projections. I see them as a musical composition. I hear them acoustically. Architecture is a world of relationships that is very, very close to my experience as a performing musician. My own response is that architecture, the way it is produced and received, is very similar to music […] every note is exactly where it needs to be. It's extremely structured. Yet its impact is totally emotional."[138]

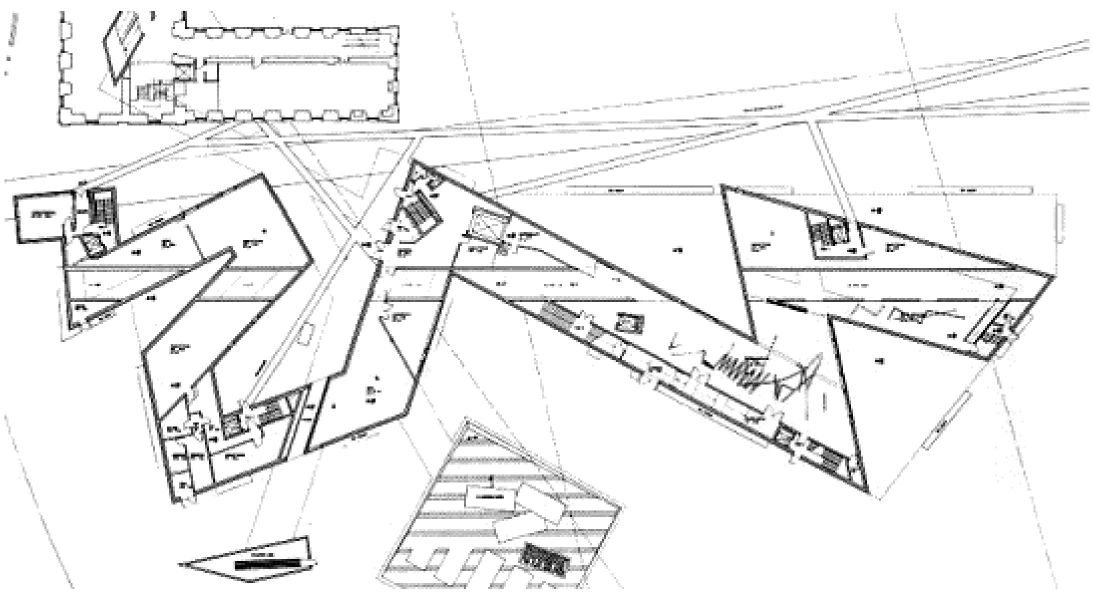

Figure 2-22. Daniel Libeskind, floor plan of the *Jewish Musem of Berlin* (1999).

[138] Daniel Libeskind*, "Counterpoint: Daniel Libeskind. In conversation with Paul Goldberger"* (2008), 12.

CHAPTER 3
THE MODEL

Overview

This section of the study is dedicated to the specific application of the compositional model, how the acoustical data is obtained, and how it is translated into musical terms. The applications are organized per area of study: the first section describes how the parameters related to frequency (pitch) are utilized, the second section describes how information regarding time is used, and the third section utilizes amplitude as a musical parameter translating acoustical measurements like the G factor. The latter also includes the possible utilization of energy ratios (i.e. lateral fraction or LF) for musical purposes.

Data Collection

The room selected for the initial application of the proposed model is the Baughman Meditation Pavilion at the University of Florida. This room has specific acoustical qualities that justify its use as an object of study.

In order to fully understand and appreciate the design elements of this building, a basic knowledge of physics and materials science is necessary. One of the most important of these topics is the physics involving the path of a sound wave from source to receiver. An enclosed space, like the Baughman Center, provides an infinite number of different paths for the longitudinal sound wave to take in traveling from source to receiver. Depending on the properties of a surface, a sound wave will experience reflection, diffraction, diffusion, or absorption when contacting the surface. The reflection of a sound wave is simply the sound wave “bouncing” off of a surface while retaining most of the sound wave’s original energy. When a sound wave encounters certain surfaces, the material will actually absorb some of the energy. An absorption coefficient (normalized values between 0 and 1) is used to evaluate the amount of sound absorption of a particular material in specific frequency bands. The coefficient is higher when the material is highly absorbent and most of the sound energy is not reflected, it is lower when the material is mostly reflective.

Structural and Acoustical Considerations

The building structure was fabricated of steel tubing bent to the shapes of the design in a Gothic style. This fact, in addition to the considerably high ceiling, has a direct acoustic consequence in the space, generating a longer RT. The shape of the ceiling (dome) as well as the lack of reflecting panels in the performance area, reduce the index of clarity and directionality of the space. According to the measurements taken from the space, the following tables show the index values according to the different locations of source (S) and receiver (R) as presented in the image of the floor plan. Each value is expressed in its own unit, related to time, amplitude or frequency (seconds, dB or Hz respectively).

Table 3-1. Data collected from the Baughman Center.

S1 R1								
F(Hz)	63	125	250	500	1000	2000	4000	8000
snr(dB)	3	22.5	30.1	30.7	26.7	30.7	35	39.8
edr(dB)	15.7	33.3	41.6	40.8	37.4	42.6	47.3	53
EDT(s)	1.38	1.55	2.62	2.55	2.17	1.6	1.49	1.06
T30(s)	2.17	1.86	2.37	2.65	2.45	1.84	1.69	1.34
corr	-0.99	-0.996	-0.999	-1	-1	-0.999	-1	-0.999
T20(s)	2.17	1.72	2.38	2.68	2.41	1.76	1.65	1.28
corr	-0.99	-0.992	-0.998	-0.999	-0.999	-0.999	-1	-0.999
Tc(ms)	192	119	174	173	139	90	68	39
C80(dB)	2.5	0.7	-2	-2.2	-0.6	1.8	4	7.1
D50(%)	40	45	30	30	37	50	63	76
G(dB)	56.9	59.3	62.2	61.4	51.1	47.5	45.2	43

Table 3-1. Continued.

S1 R3								
F(Hz)	63	125	250	500	1000	2000	4000	8000
snr(dB)	7.9	24.1	30.2	28.1	29.5	35.2	36.7	38.1
edr(dB)	25.2	33.9	40.3	38.5	40.6	48.4	49.6	51.4
EDT(s)	1.18	1.37	2.25	2.61	2.09	1.82	1.63	1.33
T30(s)	1.02	2.22	2.48	2.77	2.38	1.99	1.71	1.39
corr	-0.994	-0.995	-0.999	-1	-0.999	-1	-1	-1
T20(s)	1.02	2.04	2.38	2.77	2.27	2	1.68	1.37
corr	-0.995	-0.989	-0.999	-1	-1	-1	-1	-1
Tc(ms)	106	108	168	202	166	142	130	102
C80(dB)	2.2	1.4	-1.1	-4.4	-2.6	-1.4	-1.3	0.5
D50(%)	43	46	36	19	19	24	26	34
G(dB)	58.3	59	60	57.4	51.1	48.6	43.7	38.4

S2 R1								
F(Hz)	63	125	250	500	1000	2000	4000	8000
snr(dB)	-5.7	10.9	25.2	24.8	22.3	27.1	27.6	31
edr(dB)	15.4	24.2	36.6	36	34.4	39.8	40.3	45.5
EDT(s)	0.85	1.69	2.19	2.51	2.23	1.77	1.58	1.25
T30(s)	1	1.97	2.32	2.57	2.33	1.85	1.73	1.36
corr	-0.986	-0.998	-0.999	-0.999	-1	-1	-1	-1
T20(s)	1	1.97	2.4	2.57	2.38	1.8	1.69	1.36
corr	-0.986	-0.998	-0.997	-0.999	-1	-1	-1	-1
Tc(ms)	176	147	168	171	156	128	111	88
C80(dB)	1.5	-1.4	-2.1	-2.5	-1.3	-0.2	0.2	1.6
D50(%)	54	32	16	27	29	31	37	44
G(dB)	60.9	56.8	59	56.7	46.7	43	38	34.1

S2 R2								
F(Hz)	63	125	250	500	1000	2000	4000	8000
snr(dB)	7.8	23.3	31.9	31.3	29.9	36.8	39.8	42.8
edr(dB)	22.3	35.5	42.5	41.9	40.7	49.4	52.5	56.4
EDT(s)	1.6	1.57	2.18	2.69	2.13	1.47	1.33	0.99
T30(s)	1.62	1.9	2.29	2.65	2.51	1.8	1.64	1.33
corr	-0.998	-0.997	-0.998	-0.999	-0.999	-0.999	-1	-1
T20(s)	1.62	1.89	2.18	2.54	2.43	1.76	1.6	1.31
corr	-0.998	-0.991	-0.999	-0.999	-0.999	-0.999	-1	-0.999
Tc(ms)	100	115	135	136	104	80	61	40
C80(dB)	4.3	0.4	-0.3	1.2	1.6	2.6	4.8	6.9
D50(%)	68	37	41	44	55	55	65	76
G(dB)	58.7	57.2	58.8	54.7	45.4	43.6	41.1	37.4

Table 3-1. Continued.

S2 R3								
F(Hz)	63	125	250	500	1000	2000	4000	8000
snr(dB)	8.5	23.3	32	31.8	32.3	37.8	39	41.9
edr(dB)	25.4	37.3	43.4	43	43.5	51.2	51.9	55.5
EDT(s)	1.15	1.75	2.16	2.42	1.84	1.53	1.38	1.07
T30(s)	1.22	1.8	2.51	2.72	2.46	1.76	1.69	1.35
corr	-0.994	-0.999	-0.999	-1	-0.999	-1	-1	-1
T20(s)	1.22	1.82	2.53	2.7	2.32	1.72	1.66	1.3
corr	-0.994	-0.998	-0.998	-0.999	-0.999	-0.999	-0.999	-0.999
Tc(ms)	67	95	119	104	85	81	82	62
C80(dB)	5.3	3.6	1.4	2.4	3.7	3.2	2.7	4.5
D50(%)	77	56	49	60	62	58	52	61
G(dB)	56	56.1	57	55.9	47.5	44.8	39.7	36

The collected data reflects an interesting behavior of the room regarding the indexes of bass ratio that is the comparison between the G factor in the low and mid frequency bands or (G 125 + G 250) / (G 500 + G 1000) and bass strength, which is the subtraction between the same two values. The calculation gives a bass ratio of 1.22, which implies a strong primacy of the low frequencies over the mid-highs. This is a clear example on how the acoustical environment in which the music is performed could affect its tone color. In this case, the hall amplifies the low components of the spectrum, increasing the brittleness and muffled quality of the music performed within it. The performance space shapes vertical definition with regard to acoustical factors such as balance among the sounds of the various instruments as they reach the audience; the degree to which the tones from the different instruments in the stage enclosure blend together; the relative response of the hall at low, middle, and high frequencies.[139] Finally, it can be said that the Baughman Center colors the sounds events that occur

[139] Leo Beranek, *"Concert halls and opera houses"* (2004), 26.

within it, with a significant reduction of the high frequencies above 1000 Hz and a simultaneous enhancement of the low bands below 250 Hz.

Another relevant conclusion about the collected data is the influence that a long RT (of more than 2 seconds) can have on the clarity index and a room's definition. The terms "definition" and "clarity" are synonyms for the same musical quality. They name the degree to which a listener can distinguish sounds in a musical performance. Definition is discernible in two forms: horizontal, related to tones played in succession, and vertical, related to tones played simultaneously. In either case, definition results from a series of factors, both musical and acoustical, pertaining to a certain piece of music, played in a certain way in a certain environment. Horizontal definition is usually defined by acousticians as the ratio expressed in decibels of the strength of the early sound to that of the reverberant sound.[140] The Baughman Center has the particularity of having the longest RT in the most sensitive frequency bands for the human ear. This fact prevents the listener from clearly hearing successive events (horizontal definition), which become subsumed, as shown in Figure 3-14, into their own reflections.

The front door is reminiscent of ancient Gothic doorways and is comprised of three types of wood, maple, cherry and mahogany. Wood is one of the main components of the construction (both inside and outside) with a low Noise reduction coefficient (NRC)[141] of 0.1.

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[140] Leo Beranek, Ibid. 25 – 26.

[141] NRC is an average between the reduction coefficients from 6 octave bands in Hz (250, 500, 1000, 2000). It is a single-number rating of the sound absorption coefficients of a material, an average that only includes the coefficients only in the 250 Hz to 2000 Hz frequency range. That limitation creates discrepancies with the materials that have an identical NRC but have a radically different response to frequencies that are beyond

The side doors are constructed of identical materials and follow the same geometric patterns as the repetitive bay windows along the nave. The east Gothic (glass) window of the building covers the back section of the performance area, providing a constant view of the lake. The NRC here is also very low 0.15, favoring the existence of poly-directional sound reflections from the performance area. Those reflections, therefore, do not reinforce the sound sources on stage but increase the G factor of the space or the ratio between direct and reflected sound.

The building is constructed of three main materials with similar acoustic properties: wood, glass and marble. These materials have radical acoustical results. In particular, the exterior walls are made of natural Florida cypress, stained to reflect its surroundings. The roof system is made of tongue-and-grooved yellow pine, rigid insulation, and standing seam copper to reflect the ancient materials of medieval cathedrals. All glazing (glass) is comprised of low-E, high-energy efficient glass in three shades of green, creating an additional pattern in the glazing system.

The interior materials are comprised primarily of painted structural steel, stained Southern yellow pine tongue-in-grooved roof planking organized in intricate lacework patterns creating a dramatic vertical space nearly 50 ft. tall. The properties of the ceiling have relevant acoustical consequences such as focal points and echoes. Acoustically, concave surfaces can cause problems, as they may focus the sound in certain areas while leaving others with too little sound. Thus, vaulted ceilings as seen in Fig. 3-1 are only acceptable if the radius of curvature is less than half the height of the room (or

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the boundaries considered by the coefficient (< 250 and 2000 <). David Egan, *Architectural Acoustics,* (1988), 50 – 53.

rather half the distance from peoples' heads to the ceiling) so that the focus center is placed high above the listeners. Similarly, the standing waves can be easily avoided by creating irregular designs on the parallel walls, which would also benefit the overall level of diffusion of the space. In this particular case, the ceiling is higher than necessary for a room that is designed for speech and music; consequently, substantial areas of the room surfaces should be treated with sound absorbing material in order to control the reverberation time. However, excessive sound absorption could reduce the overall sound level (G factor) in the room. The implementation of ceiling panels to redirect the early reflections could be a proper solution to balance out the acoustical inaccuracies generated by the high vaulted ceiling without compromising the natural “liveness” of the space.

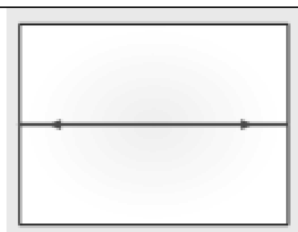
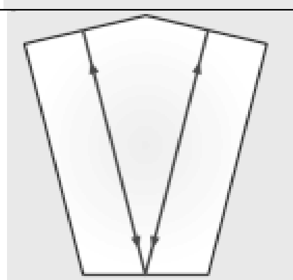
	Diagram of the standing waves and echoes that can be generated by the existence of parallel walls in the design.
	This graphic represents the undesired focal point as a consequence of the vaulted ceiling. That design feature also favors the uneven distribution of the reflections within the audience area.

Figure 3-1. Diagram of acoustic consequences of parallel walls and vaulted ceilings.

The floor material is travertine marble organized in a geometric pattern that reflects the structural logic of the building, using three shades of travertine, a device reminiscent of the ancient cathedrals after which it was patterned. Building acoustics have been enhanced by faceting the side windows to disperse sound waves, thereby "softening" the overall acoustics. The fixed seating was custom designed and locally fabricated of maple and cherry with deep blue fabric seats and backs for comfort, visual interest and color.

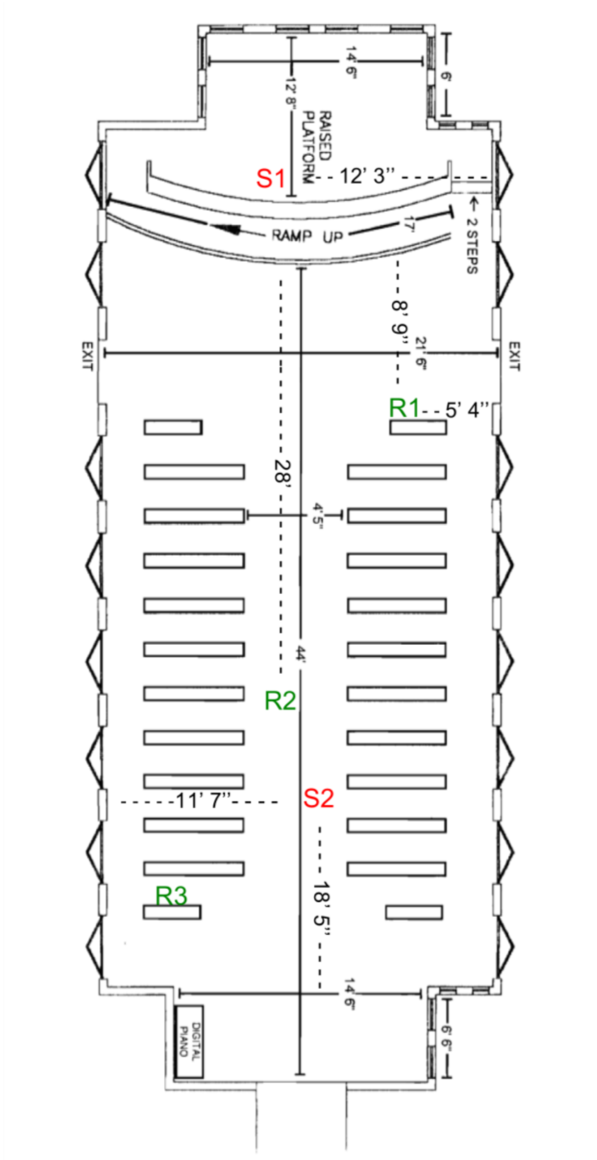


Figure 3-2. Baughman Center Meditation Pavilion floor plan with exact location of the Sources (S) and Receivers (R) utilized for the impulses and the data collection. Plan by Zona, Humburg & Associates Architects.

Parameters from Room Acoustics and their Application

These parameters are organized according to the pitch, time and amplitude domains. This is the section of the study in which the values of room acoustics actually become music.

Pitch – Frequency Response and Centroid

The frequency response of a room is the measure of the spectrum output of its response to a signal input (impulse). The centroid is where the center of mass of that spectrum is located, calculated as a weighted mean of the frequencies and their corresponding amplitudes.

In this section of the chapter, the fundamental frequency that corresponds to a tone is the only element taken into account for the calculation of the weighted mean then implemented through orchestration. All the remaining partials of the spectrum are disregarded. In that case, the center of weight between two pitches (tones) at the same amplitude with respective frequencies of 200 Hz and 400 Hz will have a center of 300 Hz as only the fundamentals are used for the calculation.

As mentioned before, the ultimate purpose of this study is to elaborate a compositional method through models for orchestration based on architectural acoustic measurements. For that purpose, the instruments are only conceived as “sine tones” (a single *x* fundamental frequency at an *y* amplitude with a *z* duration) in order to facilitate the implementation of the model when numerous sound sources are present and to control the multiple relations between center of weight, dynamics and volume of orchestration.

The collected data shows that the spectrum content of any source performed on stage is perceived differently depending on the location of the receiver.

Room centroid values obtained from the Baughman Center as an average between the centroids of eight different impulse locations within the room (everything according to the S and R locations in Table 3-2).

Room Formants - Specific Resonances:

Table 3-2. Room formants and centroid values for the different S and R locations.[142]

Location	Formant peak (in Hz)	Centroid (in Hz)
S1 R1	366	357
S1 R2	279	399
S1 R3	259	315
S2 R1	298	336
S2 R2	298	262
S2 R3	429	310
S3 R1	236	241
S3 R2	214	326
Average	298	319

Orchestrating the Centroid Values

The centroid value obtained from the impulses in the Baughman Center is less than 10 Hz off the 329 Hz or E4. Some of the following examples utilize different values in order to clarify the examples. However, some of them are specifically "tuned" to the obtained values from the Baughman Center.

As mentioned before, the centroid is calculated as a weighted medium. If the spectrum had all frequencies of equal amplitude, then the centroid would be identical as the median frequency. That situation is rare and is mainly reserved for electronically synthesized sounds. A spectrum is characterized by the different amplitude of each of

[142] Measurements obtained using PVC, sound analysis and processing software, created by Paul Koonce.

its component frequencies, which need to be weighed accordingly when making the centroid calculation.

This example shows an ideal situation where the median of this chord[143] is also the chord’s centroid (E4) because the two pitches have an identical dynamic indication.

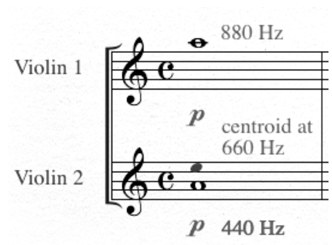


Figure 3-3. Orchestrated centroid (I).

In the next example, despite its apparent complexity, the centroid equals the median because all the frequencies evaluated are at the same amplitude.

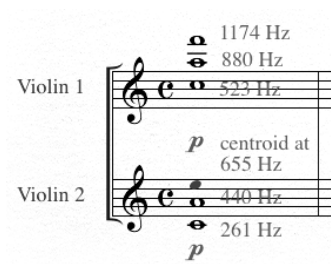


Figure 3-4. Orchestrated centroid (II).

The calculation gets more complex when each pitch has a different amplitude and duration; for that case we will use the formula of the weighted – mean in order to obtain a precise result.

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i \cdot x_i}{\sum_{i=1}^{n} w_i}.$$

Figure 3-5. Weighted mean formula.

[143] In this section of the study, the terms “chord” and “complex” refer to the same concept and are, therefore, interchangeable: group/s of two or more pitches that occur simultaneously.

In this case the centroid will increase in the direction of the pitch with higher amplitude. The high A at 880 Hz is four times louder than the lower one, pulling the centroid upwards to 693 Hz, getting to an absolute frequency that is almost a half step above (F4) from the previous example with 2 notes at the same dyamic.

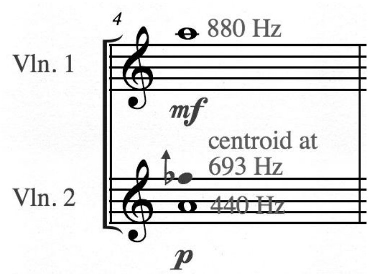


Figure 3-6. Orchestrated centroid (III), with weighted dynamics.

Those orchestrational concepts can also be applied in a more dynamic way by following the curve reflected by the values obtained in the actual room. We can use orchestration to gradually change (increse or decrease) the centroid. The following excerpt shows how the increasing amplitude of the lower pitch has a direct influence on the value of the centroid, pulling it down. The inverse effect would occur if the higher pitch increased in amplitude.

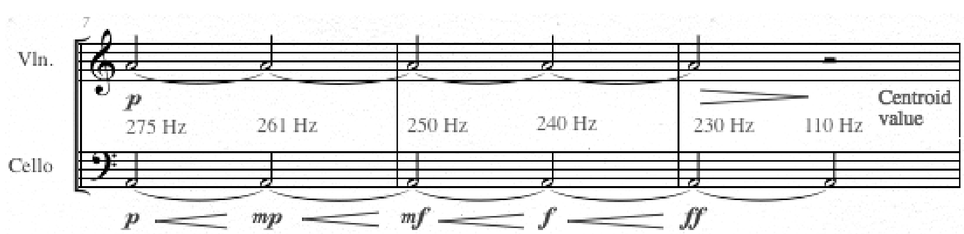


Figure 3-7. Weighting dynamics and varying centroid value (I).

To actually “tune the music to the room” the process of orchestrating the centroid values can be expanded even more. The center frequency of a room can be used to create chords that, despite their different configuration, share the same centroid. Those chords are of particular interest as they all have the same “frequency mean” and naturally expand the resonance of the room. The following excerpt shows a series of chords that have the same centroid of 440 Hz (with a maximum margin of error of 10 Hz) as if they were orchestrated using the centroid of a hypotetical room. Each note has its own dynamic indication for the sake of clarity and consistency of the example.

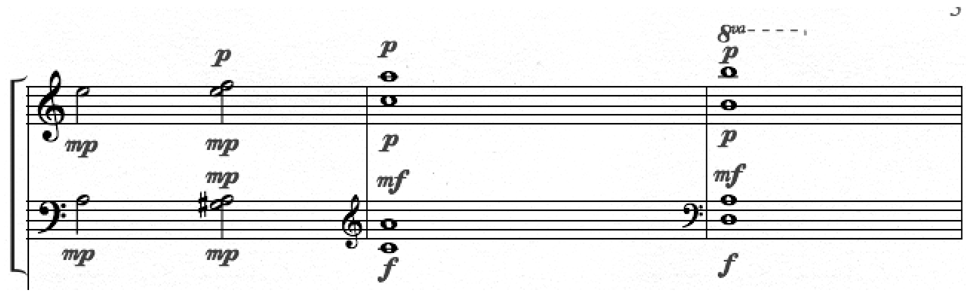


Figure 3-8. Weighting dynamics and varying centroid value (II).

This concept could be further developed by calculating the centroid of a sub-group of the components of the resulting chords in a sort of chain of centroids or “centroid of the centroid”. That concept (“centroid of the centroid”) is a compositional device that focuses on the gravitational point of a note, frequency or array of them; pitches are consirered as a whole along with their amplitudes (dynamics) that influence the location of the center of mass of a spectrum or a chord. In the following example, the initial centroid value is 660 Hz (equivalent to E5).

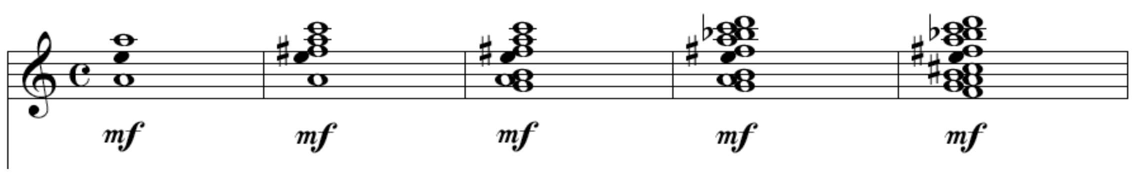
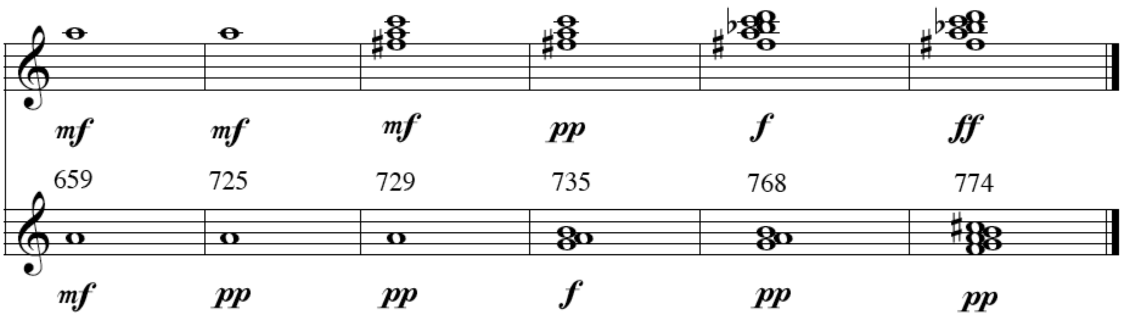


Figure 3-9. Example of a single centroid value (E5 or 659 Hz) through a series of complexes at the same dynamic level.

The upper and lower pitches (880 Hz and 440 Hz respectively) are at the same dynamic and do not alter this value. If we consider these last two pitches as new centroid values, we could think about them as new centroids and orchestrate chords around them and, therefore, still keep the overall 660 Hz of the complex unchanged.

It is important to clarify that the centroid of the centroid needs to be calculated prior to the calculation of the centroid value of the overall complex. Otherwise the values do, in fact, change.

This approach becomes more intricate when each pitch component is performed at a different dynamic (amplitude). Each pitch gets weighted by 10 dB per dynamic indication[144]. In order to keep the same centroid value on an E5, the complexes in the following example justify the implementation of micro-tunning. The development of the complex is similar but with a different interval configuration.



* These complexes are averaged using the concept of the centroid of the centroid, where the centroid of each group of pitches (in this case grouped on each staff) is obtained first to then utilize it in order to calculate the centroid of the whole complex. That is the reason for the small variations of the values. If each complex was weighted individually, the results would change more noticeably.

Figure 3-10. Weighting dynamics and varying centroid value (III).

The frequencies that correspond to the center of weight of the complexes respond to the weighting values coming from the amplitude domain. In addition to that, it is a remarkable fact that those centers correspond to pitches that are not present in the

[144] According to Tables 1-2 and 1-3.

complexes, E5 (659 Hz) in the first one and G5 (774 Hz) in the last one. This compositional system facilitates the elaboration of pieces around pitch centers that are, potentially, never revealed. Unlike musics in which the center of gravity establishes its aesthetic primacy as it emerges, this model proposes the opposite approach, where the center of weight can, potentially, never surface and still remain the essential foundation of the musical composition.

System of the "Weighted Complexes"

The "weighted complexes" are groups of two or more pitches that occur simultaneously and are governed by the weight of their components. The weight of each of the components is calculated considering its frequency, duration, and amplitude (dynamics). These complexes are not built upon any interval vector or functionality within a key, but rather they are built around a center of weight given by a frequency centroid value obtained from an enclosed space. This single value represents the implicit core and gravitational center of the complexes built around it, and is based on the centroid value that, in this system, operates like the key center in a tonal environment. A musical composition could be structured upon centers of weight based on any frequency values. These centers of gravity could be easily implemented, for example, to determine the overall form of a work, with a hypotetical A section built upon a centroid value of 200 Hz that "modulates" to a B section with a centroid of 500 Hz to finish in a C section composed around 660 Hz. Unlike tonal music, these centers of weight can be effectively present or just implied. In the first case, the pitch corresponding to the center of weight (i.e. 200 Hz) needs to be present as a written G3. In the second situation, that center is the implied resulting mean between two pitches (i.e. two pitches with frequencies of 100 Hz and 300 Hz respectively that are at the same dynamic level). The latter situation represents a particularity as it favors the construction of a musical composition around pitches that could potentially never appear in the work. Unlike tonal music, the center of weight can remain unreveiled throughout a composition and still be its gravitational center.

This system justifies the use of microtonality as a natural consequence of the numerical calculations between frequency values that do not necessarily correspond to tempered pitches. The method also establishes a direct interdependence between the chosen instrumentation and the center of weight of the composition. The extreme (lowest and highest) pitches of a complex fix the boundaries of its center weight. In the previous example, the pitches that correspond to 100 Hz and 300 Hz determine the low and high boudaries for the center. In the same line of thought, the instrumentation chosen for a composition has a direct influence on its center of weight. The initial limitation is given by the extreme registers of the performing forces. In a piece composed for flute duo (instruments with a B foot), for example, the center of weight would never go above 2346 Hz or below 246 Hz. A piece for one or two pianos would necessarily be framed between 27.5 Hz and 4186 Hz. In a tonal composition, the instrumentation does not have an influence on the tonal scheme of the work, a piece for any instrumentation could potentially go from any key to any other key. Thinking in terms of center of weight, the relations between instrumentation and center of weight is radically different as the instrumentation is the boudary for the centroid. A composition for two flutes can not have a center weight at a frequency that exceeds the low and high extreme registers of the flute itself. The choice of instrumentation is, then, the first limitation to the mobility of the centroid.

At first sight, it can be seen that symmetric complexes (i.e. diminished and augmented) already have their center of weight in their axis of symmetry. That concept is initially valid if we do not consider the amplitudes of each of the components, or if the amplitudes are all equal. Symmetric complexes with components of unequal amplitude have a centroid that does not correspond to their axis of symmetry.

In one of the previous examples each of the components of a complex were "weighted" according to their amplitude altering in this way the centroid value. Another important weighting element is the duration of each of the components of a complex. We not only need to consider amplitude, but also the duration and its influence on the centroid. If we apply the same weighting principle to the durations, a longer component becomes more influential in the value of the centroid. A complex with two pitches at 220 Hz and 660 Hz with the same duration and amplitude has a centroid value of 440 Hz or A4. If the higher pitch is louder than the lowest by three dynamic indications (***mp*** to ***ff*** or 30 dB), the resulting centroid value is then raised to 455 Hz. Weighting further, if that high pitch at 660 Hz is not only 30 dB louder but also two times longer than the lowest pitch at 220 Hz, the centroid value is pulled up even more to 485 Hz (8 Hz flat from B4) as a natural result of the weights (amplitude and duration) added to the component. The following example shows a musical application of the duration of an event as a weighting factor, where the centroid is "pulled up" towards the E5 on beat 3.

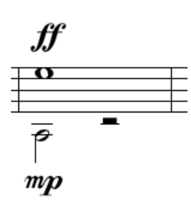


Figure 3-11. Duration as a weighting factor.

The durations are weighted in a similar way as the amplitude, thereby establishing a parallel with musical notation. In this way, amplitude and duration are equally influential and can be utilized compositionally to counter balance each other. The following chart shows how the musical durations are considered, in the proposed model, in relation to their weighted values. The system simply maintains the durational relation between figures, which are multiplied by 10 in order to balance the way dB values are paralleled with dynamics.

Table 3-3. Note rhythmic values and their respective weight.

Note value	Duration (in beats)	Weighting value
whole note	4	40
half note	2	20
quarter note	1	10
eight note	½	5
sixteenth note	¼	2.5

Time I – Reverberation RT

The reverberation (R60) of a room is the amount of time that it takes for a sound source to become inaudible after that source has been removed. Generally, in acoustics, a sound is considered inaudible when its amplitude has decreased by 60 dB from the original. In some cases, the high level of ambience noise reduces the measuring range to less than 60 dB. In those situations, the RT is measured using only the initial decay time in a narrower amplitude range of 15 dB or 30 dB. The following example shows an ideal case A where the sound decay of 60 dB can be measured completely, and a more "real" case B in which the 60 dB can only be projected using the slope of the early decay time.

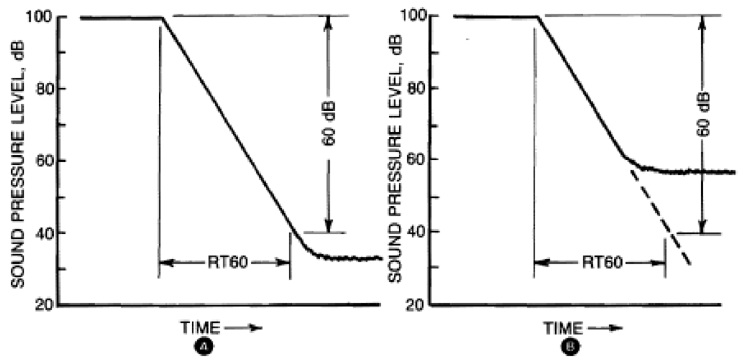


Figure 3-12. Graphic representation of a 60 dB decay envelope.

Wallace Sabine conducted the pioneering research concerning room reverberation and the amplitude of sound. When working at Harvard, he determined that there was a direct relation between the volume of the room and the reverberation time:

T = 0.05 Volume / A (absorption coefficient in sabins)[145]

Other acoustical properties that can influence this criterion are 1) the shape and proportion of the room; 2) the absorption coefficients of materials in interior walls, floor, seating area and ceiling; and 3) the seating capacity of the hall, the latter being an important factor in making measurements for a design. The following list further explicates these three concepts with respect to the Baughman Center.

- Shape and proportion: the Baughman Center has a high dome that reinforces the G factor of the room by increasing the amount of reflections. Conversely, the parallel walls facilitate the existence of standing waves and/or echoes. The rectangular shape is not the most recommended by acousticians. Moreover, the sound reinforcement structure of the room does not reduce the ITDG as it would be desired for musical performance.

- Absorption coefficients of the interior materials: the interior walls, ceiling and floor are mainly wood and glass, highly reverberant in most frequency bands. High

[145] M. David Egan, "*Architectural acoustics"*, 63.

ceilings and parallel walls with reflective materials are synonyms with long reverberation time and low intelligibility. In addition to that, they do not distribute the sound's energy evenly throughout the listening space.

- The seating capacity of the hall: the audience area is limited to no more than 100 members. This can potentially reduce the RT, but by no means control it.

The Baughman Center has an average reverberation time (between frequency bands and different locations of source and receiver) of 2 seconds. If we take the bands where the human ear is most sensitive (250 Hz – 4000 Hz), the averaged result is slightly longer 2.2 seconds. This is not a minor fact, especially if we consider that when a musician performs, the speed at which the performer plays has a vital relationship with the acoustics of the hall. In particular, the speed at which successive tones follow one another interacts with reverberation time and, thus, shapes what the audience hears. The faster the musicians play, the more notes pile up under the same RT envelope.

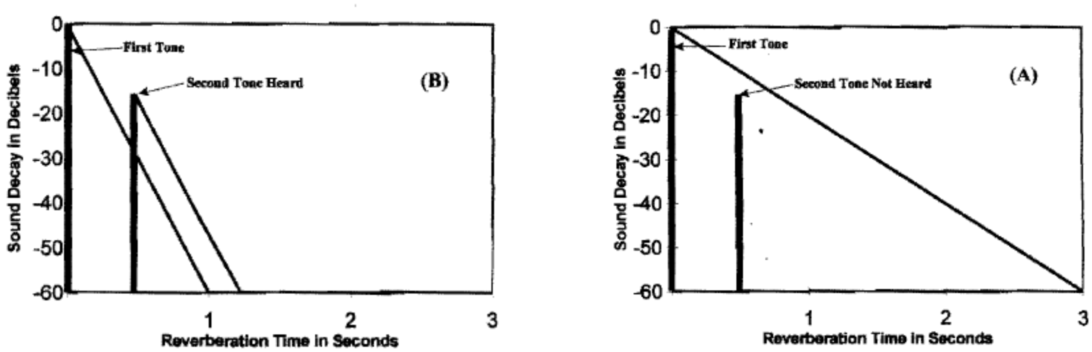


Figure 3-13. Graphic of two successive tones performed in rooms with different RT envelopes.

Where the speed of successive notes as represented in Figure 3-13 increases, the second tone would move to the left because the time between the two notes would become shorter. If the speed is high enough, the second tone will fall below the reverberation envelope of the first tone. Even for a RT of less than a second, the attack of the second tone would become inaudible. If RT = 0, the notes will stand out clearly whether played quickly or slowly, just as with music outdoors.[146]

Orchestrating the Reverberation

In this musical example, we can see the performed sound and the actual result with a 2.2 second reverberation time that corresponds to the values obtained from the Baughman Center.

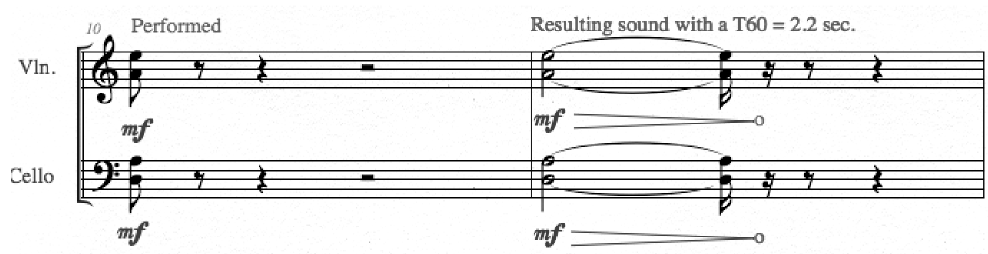


Figure 3-14. Orchestrated RT (I).

The tempo marking of (quarter note = 60) facilitates the translation between musical values and time. The RT value obtained from the Baughman Center can now be embedded in the music through the orchestration.

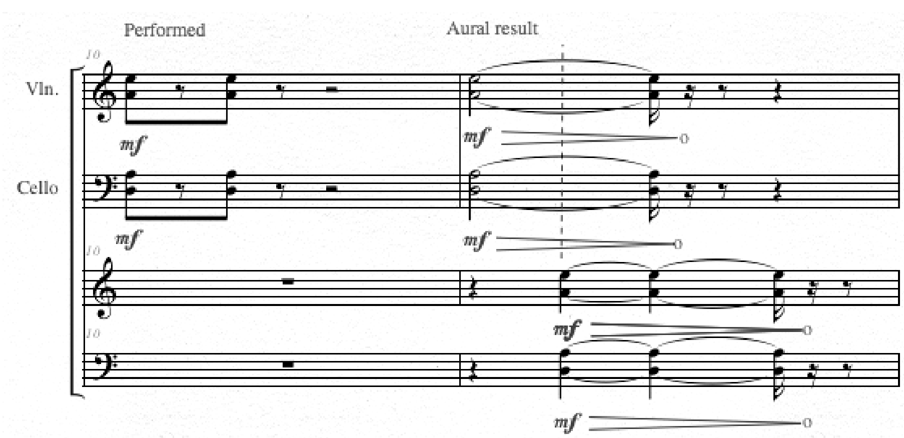


Figure 3-15. Orchestrated RT (II).

[146] Leo Beranek, Ibid. 24.

When two chords are performed in succession, meaning the attack of the second one within the decay tail of the first one, the result is of particular interest. The excerpt in Figure 3-15 shows a standard accompaniment pattern for string players and its actual aural result when performed in a room with a RT of 2.2 seconds. The second chord of the pattern is performed 1 second after the first one, in the middle of its decay tail where the initial chord still sounds but 2 ½ times softer.

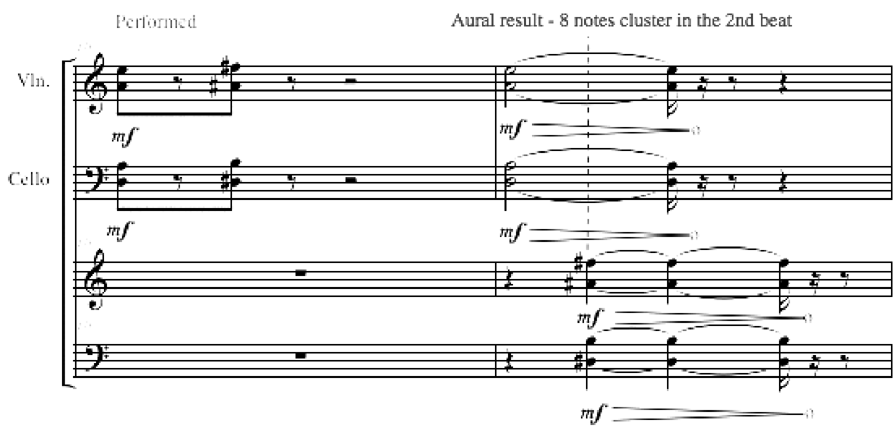


Figure 3-16. Orchestrated RT (III).

The musical consequences of that have an impact upon rhythm, dynamics, harmony and texture:

- Rhythm: its definition gets blurred. Succesive attacks are atenuated by the prolonged ring of the previous ones.
- Dynamics: the intensity gets increased. The first attack is ***mf*** , the following one is ***mf*** plus the reverberation of the previous one. The succesive increments are particularly perceivable when the same chord is played several times within the total duration of the reverberation time. The phenomenon is explained clearly by Blesser[147] when he shows in a diagram how, in very reverberant spaces, the reverberant sound can overpower the direct one.
- Harmony: the harmonic changes can become unclear because of the fact that, in some situations, two different chords will ring simultaneously. This quality can be used as a compositional device, where harmony could be the result of the overlapping reverberation of single notes.

147 Barry Blesser and Linda Ruth Salter, *"Spaces speak, are you listening?"* 142 – 143.

- Texture: the written passage shows a monorhythmic-polyphonic texture, which becomes polyrhythmic-polyphonic due to the RT.

The excerpt in Figure 3-16, the T60 of 2.2 second facilitates the aural illusion of an 8-note cluster on the second beat of the measure, which is something, presumably, never intended by the composer.

The excerpt in Figure 3-17 is a simultaneous complex that is performed at the same dynamic and that is equally spread along all the frequency bands measured. As those bands decay at different times, the result becomes evocative of the space. The excerpt's complex is built around the centroid value of the room at ≈ 329 Hz or E5 combining data from both the time and frequency domains. The tempo is MM = 60. The whole passage recreates in musical notation the acoustical data taken from the Baughman Center. This example could be developed further if we utilize different reverberation times per frequency band.

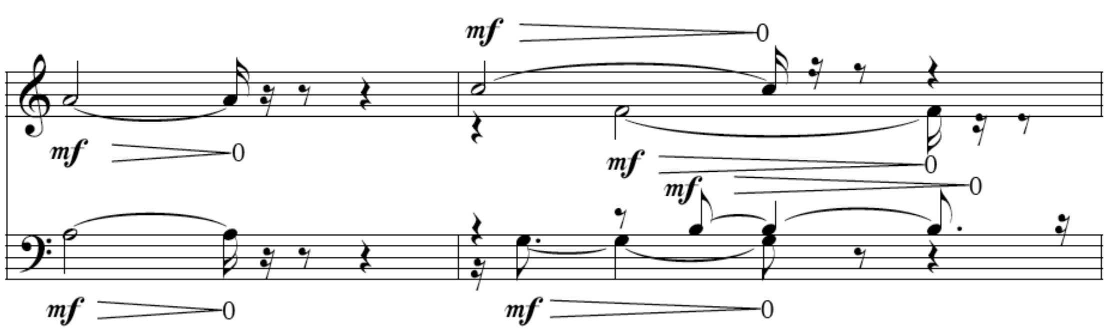


Figure 3-17. Orchestrated RT per frequency band (I).

The following example considers not only the centroid value obtained from the room, but also the RT per frequency band. Now, the decay times respond not to the average RT value, but to the specific values as shown in the initial chart from this Chapter (Figure 3.1).

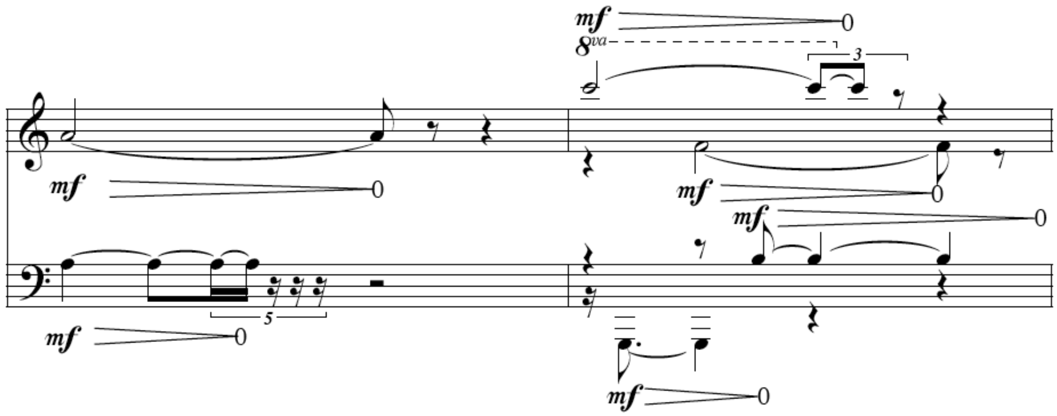


Figure 3-18. Orchestrated RT per frequency band (II).

Due to the particularities of the collected data and for orchestration purposes, the RT values are averages from all impulses in three main band subgroups (63 to 125, 250 to 1000, 2000 to 8000). The values per group are (in seconds) 1.7, 2.5 and 1.65 respectively. The orchestration example was composed using the same centroid value with different pitch distribution, and independent RT per band. All the values are according to the measurements obtained from the Baughman Center.

Time II – Rhythm of the Early Reflections

The rhythmic implication of the RT is only limited to duration and enveloping. Rhythm, as the succession of sonic events in time, is not taken into account. Even though, the “rhythmic identity” of an enclosed space can be extracted from the temporal succession of the early reflections of an impulse. The early reflections were chosen for the proposed model because they unequivocally define the dimensions of the enclosed space. As they travel a longer path, the amount of time it takes the first reflected sounds to reach our ears give us clues as to the size and nature of the listening environment.

For the proposed model, the impulse S1 R1 was utilized. The Acoustic Tools software helped to measure the time between the first 10 reflections after the direct source. Those reflections were separated by the following times (in milliseconds):

Table 3-4. Delay times of the first 10 early reflections.

Reflection	1	2	3	4	5	6	7	8	9	10
Delay time (ms)	3	4	5	8	9	12	22	24	25	29

These minute time delays are initially irrelevant for the human ear, which cannot differentiate events happening between the first 25 ms. For echoes delayed less than 25 ms., there is almost complete subjective integration of signal and echo. Although they are not heard as discrete echoes, their energy is not lost and contributes materially to the apparent level, quality and intelligibility of the sound. In fact, the ear performs this integration of the direct and reflected sound. Reflected energy arriving at the ear within 25 ms. is integrated with the direct sound and is perceived as part of the direct sound as opposed to reverberant sound. These early reflections increase the loudness of the sound.[148] Despite that fact, the proportions and placement in time of the attacks of each of the reflections can easily become a relevant compositional consideration. First, in order to fully extract the rhythm of the reflections, we need to remove the initial time reference to the direct sound, starting from 1. That will give us a new set of values that are completely isolated from their source and original unit.

Table 3-5. Values of the first 10 early reflections.

Reflection	1	2	3	4	5	6	7	8	9	10
Value	1	2	3	6	7	10	20	22	23	27

[148] F. Alton Everest (2008), *“Master handbook of acoustics”.*

The sequence of values corresponds to the architectural design of the Baughman Center and the location of the S1 R1 impulse. The first five values come from the closer side walls and the stage (in relation to the location S1, see Figure 3-2), the values after those are increasingly more separated corresponding to the reflections coming from the back walls (from the building's entrance). The difference between reflections 6 and 7 is noteworthy, and represents one of the "rhythmic" characteristics of a specific location in this particular room.

Orchestrating the Rhythm of the Early Reflections

The translation of the obtained values into rhythm can be achieved in different ways. If the values originally come from delay times in ms., the musical translation of them could simply be *v* * 1000. In that way, we keep the time proportion between events as well as their temporal origin. Thus, this 10-values-27-seconds rhythmic pattern is acoustically related to the studied room and at the same time musically significant.

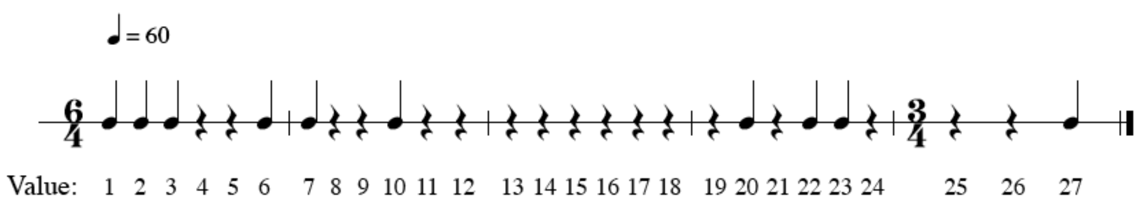


Figure 3-19. Rhythmic structure extracted from the early reflections.

Another approach is to only keep the temporal proportions between the obtained values without any reference to the original unit of time. The composer can now freely choose a time unit with the corresponding dissimilar result; the ten events (corresponding to the reflections) are placed in a varying time spam. Those events occur at the same ratio as the early reflections but are expanded or compressed according to the composer's chosen unit. Durations and pitches are freely decided provided that they do not compromise the placement of the attacks.

The excerpt on Figure 3-20 is built upon the pitch classes of an ascending chromatic scale (F# to D#) that are organized in time according to the proportions extracted from the early reflections of the Baughman Center.

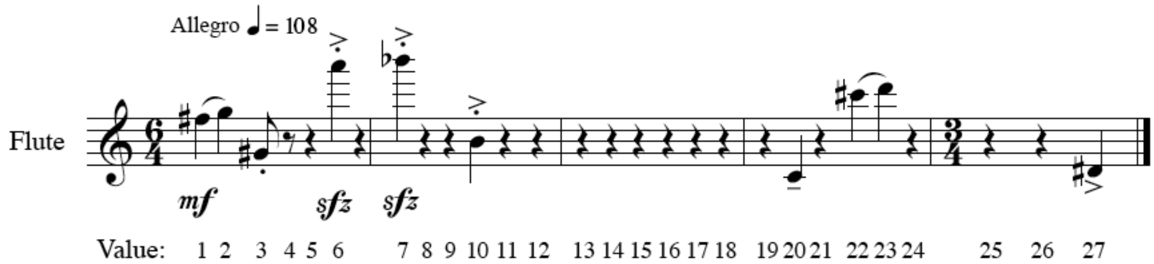


Figure 3-20. Orchestration of the rhythmic structure extracted from the early reflections (I).

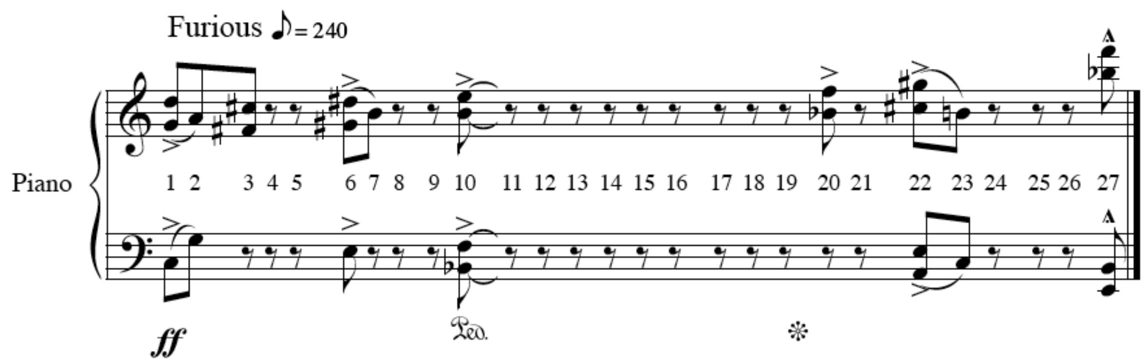


Figure 3-21. Orchestration of the rhythmic structure extracted from the early reflections (II).

The integral application of the rhythmic elements results in a musical example that takes into account the placement of the attacks of the sonic events (coming from the early reflections) as well as their resonances, which come from the RT value.

Figure 3-22. Orchestration of the rhythmic structure extracted from the early reflections (III). For string quartet, also considering the room's RT value of 2.2 s.

Amplitude (Dynamics) – the G factor

This criterion differentiates the amount of sound pressure coming directly from the source from the one that is added by the room. This addition of sound pressure provided by the room is both related to the level of the "quiet" in the room as well as the amount of sound reflections that it generates.[149]

An impulse response can be used to determine the G factor of a room in several ways:

- The level of the quiet reflects by itself the lowest threshold of ambience noise in a room (a room with a quiet of 35 dB is louder one with a level of 30 dB). This criterion is very dynamic and can reflect differences within the same space. In the University Auditorium at UF, for example, the value increases by a 30% when the decibel meter is located towards the back of the room. This level also changes depending on the acoustic calendar. At night, it is considerably lower, considering the reduced traffic and amount of people in the area.

[149] Leo Beranek, Ibid. 509.

- An impulse response of a source in an anechoic room (SPL free) can be compared to one of the same source in the room (SPL hall), the difference between them is the loudness level, or G factor.

The equation calculates the difference between sound pressure level in the hall and in a free field (anechoic).

$$G = SPL_{hall} - SPL_{free,10m}$$

Figure 3-23. G factor calculation.

The following graphic shows how reverberation builds up the level of loudness to the listener who perceives direct sound + reflections.

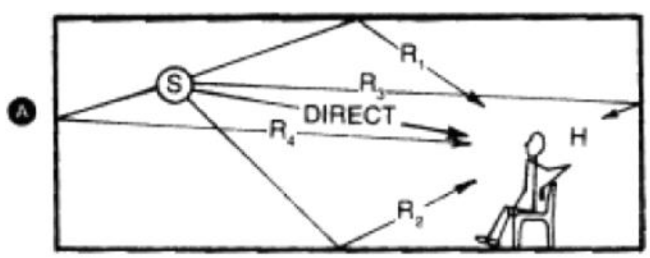


Figure 3-24. Impact of the G factor in the listener.

Sound absorption coefficients have an inverse relation with the loudness criteria. If a room has a low absorption coefficient in the surfaces of interior walls, ceiling and floor, the loudness will increase. In addition to that, mitigating undesired sounds that increase the level ambience can reduce the loudness level as well.

Orchestrating the G Factor

The G level is closely related to the concept of definition or clarity of a room. The terms "definition" and "clarity" are synonyms for the same musical quality. They name the degree to which a listener can distinguish sounds in a musical performance. Definition is discernible in two forms: horizontal, related to tones played in succession, and vertical, related to tones played simultaneously. In either case, definition results from a complex of factors, both musical and acoustical, a certain piece of music, played in a certain way, in a certain environment. Horizontal definition is usually defined by acousticians as the ratio expressed in decibels of the strength of the early sound to that of the reverberant sound. Thus, if the definition, in decibels, is a positive quantity, the early sound dominates. If negative, the strength of the reverberant sound dominates. If zero, they are alike.[150]

The implementation of the G factor in the proposed model is the ratio between the G values of certain frequencies. Specifically, the mid-low bands 63, 125, 250 and 500 divided by the mid-high ones 1000, 2000, 4000 and 8000. That operation returns a ratio of 1.35 meaning that the room's loudness has a higher ratio of lower frequencies within the overall G factor. This choice was made in order to accurately represent the room's spectral color, which in this particular case is clearly oriented towards the mid-low bands.

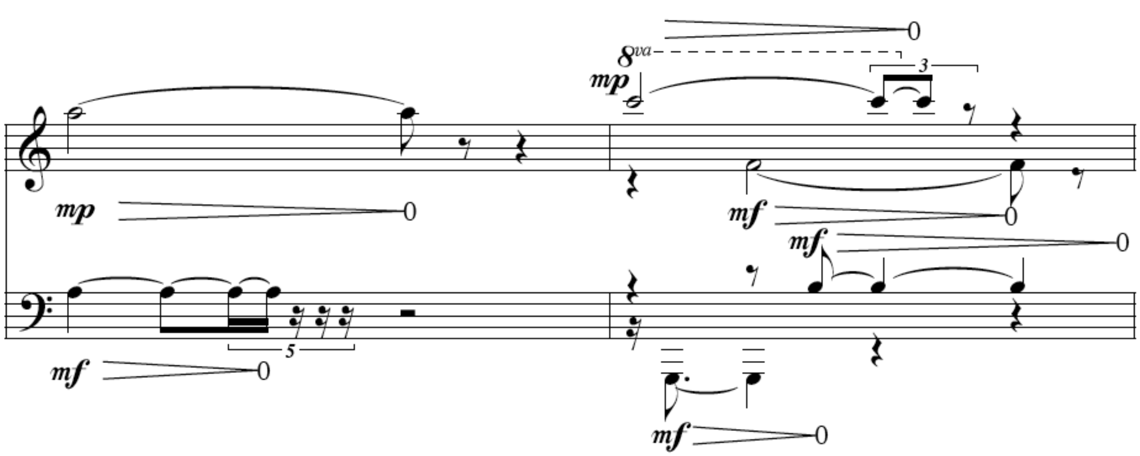


Figure 3-25. Combinatorial example (I).

[150] Ibid. 25-26.

The previous example shows an application of the preceding principle. The problem here is that the equivalencies between amplitudes and dynamic indications established initially for the model are structured in doubling values (***p*** is twice as loud as ***pp*** or 10 dB more) and the ratio shown by the room measurements are less than 2. In this case, and to make the translation musically interesting, the G value between mid-lows and mid-high is rounded to 2, so the frequencies below 500 Hz are orchestrated twice as loud in relation to the high ones.

Figure 3-26. Combinatorial example (II).

Another feasible and musically relevant application would be to consider the G factor more strictly related to the direct sound, suggesting through the orchestration the idea of the reflected sound ending somehow embedded in the direct source. In order to achieve that effect, a polyrhythmic and monophonic texture is necessary as well as an accurate dynamic relation between direct source and reflected one.

The example on Figure 3-26 shows one of the three possible scenarios. The excerpt orchestrates a negative G value (louder direct source, doubles the amplitude of the reverberated sound). Despite that fact, the G factor could be positive (the reverberated sound is louder), or equal 0 (when direct and reverberated are equal).

That data could be easily translated into the same excerpt by adapting the dynamic indications. This particular example embeds an unambiguous aural representation of a direct sound source and its posterior reflection. The tempo is MM = 60 and it could be a potential fragment of a composition for two pianos, or string ensemble.

The ITDG evoked (between the direct source and the first reflection) is of 1 and 1.5 seconds respectively; that value rarely occurs as an actual acoustical measurement, but it is implemented to suggest the existence of a reflection within the composition. If actual values of ITDG (normally around 80 ms in concert halls) were used, every orchestration attempt to translate them into a musical passage would be unproductive as the human ear unifies musical events separated by 80 ms or less. In addition to that, it would also be impractical to provide the performers with 80 ms rests. Regarding ITDG, the musical relevance prevails over the dogmatic numerical accuracy.

We naturally arrive at a creative application of the model, in which the acoustical data is no longer evident but still present. The resonances are orchestrated with a decreasing G factor also taking advantage of the idiomatic orchestration resources of the string ensemble; the evocation of the decreasing reflections is also achieved by the non-vibrato effect, which helps differentiate them from the original source. The bowings also help to reinforce the idea of what is direct source and what is not, the down-bows are utilized to give more emphasis to the direct sources and up-bows to suggest the milder attack of the resonances. Color contrasts are also reinforced with the *sul-ponticello* effect.

Figure 3-27. Combinatorial orchestration example of the G factor for string ensemble.

The initial centroid value example (as seen in Figure 3-3) developed into a musical excerpt of 10 seconds of duration that could continue to evolve in complexity and musical interest with the implementation of other simultaneous complexes and volumes of orchestration.

CHAPTER 4
APPLICATION OF THE MODEL

Personal Motivations and Application of the Proposed Model in a Musical Composition

As a composer of music, I am interested in developing creative processes that evolve from concepts inherent in sound itself. The idea of going from sound to sound through the process of music composition is one of the main goals of this study. Alvin Lucier, Tristan Murail, Jean Claude Risset and Olivier Messiaen, are just a few examples of artists that, deliberately or not, had a similar intent.

In the case of the proposed method, it is my desire to continue a path that Iannis Xenakis did not explore. He explicitly mentions in his *Formalized Music* that he did not take into account elements from architectural acoustics into his compositions. One can appreciate his matrixes and probability studies and their application into music; his need of an initial sketching stage of graphic notation in order not to interrupt the flow of ideas is also remarkable. Despite those facts, I believe that he left one path uncharted; all the initial inputs that allow the generation of stochastic studies and matrices are human decisions, those numbers do not come from any other place than the composer's mind. That initial input data was that which I wanted to connect with sound and, more particularly, with the properties of sound occurring in enclosed spaces. By doing this, I intend to elaborate a method that is based on vectors and numbers that are not a product of the composer's creativity, but rather specific values taken from an acoustical measurements.

In the initial stage of the study, I had to determine which parameters of room acoustics could be musically relevant. The initial broad classification was done according to the three main domains of music: time, pitch, and dynamics, that had a direct correspondence with fundamental concepts of room acoustics: time -> reverberation time (RT), pitch -> frequency, and dynamics -> amplitude. These analogies clarified the scenario and supported the meaningfulness of the method. Another concept that influenced this study is the concept of proto and meta instruments proposed by Barry Blesser and Linda Salter in *Spaces speak, are you listening?* This concept is based on the interdependence of the direct vibrations of musical instruments and the indirect ones provided by the space through which these vibrations are propagated. Going further, this idea reinterprets the concept of what is "truly" the sound of a musical instrument. A tone of any musical instrument is provided by its direct vibration and also by the vibrations provided by the room. If we think in those terms, the daily practice of a musical instrument becomes an incomplete activity, as there is a decisive spectral component to the tone quality that is usually beyond the control of the instrumentalist. Consequentially, the practice of an instrument becomes quite complex: the performer must address the specific technical difficulties of her instrument, and work on tone quality considering (at the same time) the added acoustical features provided by the room. Practicing becomes even more complicated if it is done in an open field. In that particular case (like marching bands, for example), the instrument remains as an incomplete proto instrument and the performer must adapt herself accordingly.

Following Blesser and Salter, the room is, then, a passive component of any instrument's timbre, a passive component that is revealed when it gets excited. Music is composed for instruments that, when performed indoors, necessarily embody the acoustical qualities of the space. If we accept this fact, then the idea of composing music that is not indifferent to room acoustics becomes a natural extension of Xenakis' line of thinking.

An additional motivation for this study was the fact that architectural acoustics and music share similar concerns with respect to sound and its components. Moreover, the two activities are almost identical processes if we consider them before their respective materializations. The acoustical design of a hall, for example, is an actual orchestration, were the architect decides which frequencies to reinforce and for how long. In the reverse example, the composer is the acoustician of a piece of music that through the orchestration, handles sound sources and their reverberations. It is not by mere chance that Xenakis and Libeskind had such a similar system through which their work was conceived and constructed.

As mentioned before, it is important to reiterate that one of the purposes of this study is to complete the circle that starts by analyzing properties of sound. That whole progression ends with a sonic manifestation: a piece of music. That piece is the final section of the study and represents a creative application of the compositional model. The piece is entitled *Colors* and is written for full symphonic orchestra. As expressed in the program notes, the work is "an exploration of the endless orchestration mixtures offered by the ensemble and their unique timbres". Resonances are obtained through orchestration in numerous places throughout the work. In the excerpt, on Figure 4-1 the brass section performs a resonance to the abrupt ending of the sustained trill in the woodwinds. The chosen pitches as well as the even volume of the orchestration help achieve the desired effect. In the excerpt on Figure 4-2, the resonance is orchestrated as a selection of partials from a fundamental tone that in the example appears as the lowest note. In addition to that, the pitches that represent the resonant frequencies (implying a room response) have a different decay time in a similar fashion as suggested in the examples of the proposed model.

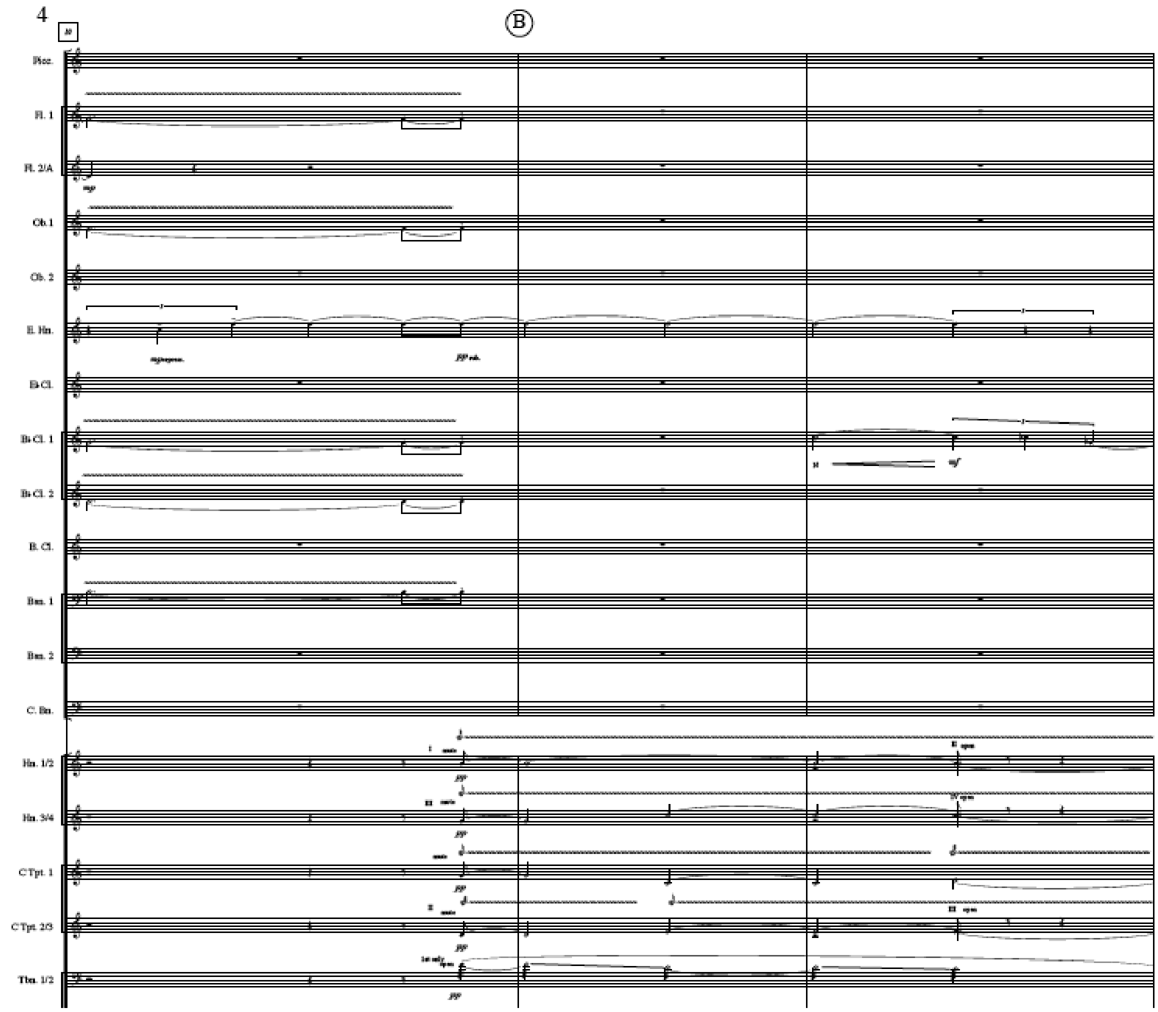


Figure 4-1. Example of orchestrated resonances in *Colors* measures 10-12.

A similar phenomenon occurs in measures 47 - 48 where the *tutti* operates as an impulse that bursts on beat three of measure 47, this being a polyrhythmical pattern in the strings and its consequent room response. In this case, the room decay is orchestrated as a gradual fade out following the acoustically appropriate spectral envelope, where the high frequencies decay faster than the lower ones. This idea is also treated more freely in the manner of “impossible resonances” where the lower frequencies decay first. That thought results in a particular design interest as it represents a palindromic construction of resonances around a fundamental pitch, which produces illusory resonances above and below it. There is a specific example of this idea in m. 92 where the resonance is orchestrated below the high G6 harmonic in the solo violin. The section of the work that develops after that moment combines illusory resonances with the drama of the increasing reflections.

Figure 4-2. Example of orchestrated resonances from measures 97-101.

In this piece, the application of the model is approached with the utmost creativity, favoring the flexibility of the implementation of the obtained data. In the previous example, the pitch content is not related to the centroid value obtained from the room, but rather to the harmonic series of a given fundamental tone. Despite that, the RT times suggest the ones obtained from the measurements. The volume of orchestration in the work was arrived at by applying the model. Measures 110 -113 are constructed upon the idea of a constantly increasing G value which is made manifest through a monophonic-polyrhythmic texture with an increasing orchestrational volume. The successive unison entrances on a D4 evoke non-decaying reflections that initially recall the loudness obtained from the Baughman Center. That texture gradually transforms into an illusory aural space where the reflections become louder than the sound source (as if the room could become more and more reflective). The metaphoric approach of this particular section puts forward a personal aesthetic vision in the application of the model; the drama comes from the utilization of the G value, not from the value itself. My main interest here was to create the illusion of a morphing space that is only revealed by its aural reactions. The listener stays immobile while the room “mutates”.

Every enclosed space offers a unique acoustical configuration, thus, every piece of music composed according to the application of this model and based on those distinctive qualities, would have its own identity and therefore "sound" different. That being so, it must be stated that not all rooms have the same musical potential. Paradoxically, the spaces that have the most acoustical "imperfections" are the most suitable for the application of the proposed model. A room with a "perfect" acoustical design has the following general properties:

- Is well balanced (every audience member perceives the sources at the same level).
- Has a natural frequency response that enhances the inherent qualities of the sources without adding or subtracting anything to them.
- Its reverberation time is between 1.5 and 2 seconds and is considerably even all throughout the frequency spectrum (this is also related to the room's response).
- Its G factor is negative (meaning that the reflections are always softer than the direct source).
- Its LF coefficient is well distributed between left and right, the ITDG for music is below 80 ms (the sound source coming from the performance area gets reinforced)
- The design avoids parallel walls and triangular domes that could add echoes and uneven distribution of the reflections.

These characteristics are examples of what a reasonable acoustical design should fulfill, and many other properties could be added to the preceding list.

Figure 4-3. Polyrhythmic monophonic texture in *Colors* as an example of an illusory increment of the G value.

On the other hand, an "imperfect" acoustical design can have the following general characteristics:

- Is “uneven”, meaning that its frequency response is “too colorful” (reinforces certain frequency bands over others).
- Has an extreme RT value of more than 2.2 seconds or less than 1 second (even with different times within the same space).
- Its G factor could be positive (where the reflections are “louder” than the direct source).
- Has an unevenly distributed LF index between left and right.

- Its design favors the existence of echoes or uneven reflections (due to parallel walls or vaulted ceilings, for example).

I previously mentioned that acoustically imperfect rooms better suit the application of the model because of the variety of the data they offer, they are less uniform and varied, all qualities that are acoustically questionable but musically desirable. The Baughman Center is acoustically “problematic” and that is why it was chosen as the source for this study.

Room responses have the particularity of having similar amplitude envelopes. Earlier or later, they inevitably decay; like the piano, a room response offers very little control of its amplitude envelope after it is excited. That is the reason why, in a compositional method that uses architectural acoustics as its basis, having the option of an increasing G factor becomes so relevant. It allows the composer to consider the indispensable idea of a crescendo that otherwise would be completely negated. A model that does not offer this option would embed its own restrictions in the music.

Data Collection Details

The acoustical data from the Baughman Center included in all the tables in chapter III were obtained using different types of impulses (sources or S): balloons, dodecaphonic speakers, and frequency sweeps. Those sources were recorded (receivers or R) using an M-Audio Microtrack II portable recorder with an Electret stereo microphone. The recorded sound files were processed and analyzed using the software Acoustic Tools and WinMLS. The latter software was specifically employed to generate maximum length sequence signal sweeps, which were amplified by a JBL EON15 G2 Portable Powered Loudspeaker System and captured by an Earthworks microphone.

Ideas for Future Research. ‘Impossible’ Spaces and Other Thoughts.

This study is far from being exhaustive, engendering a great deal of potential for further development. The more I research the subject, the more questions arise. The following topics are tangential curiosities. They could become objects of study of the relations between music and architecture and, more specifically, about musical composition based on acoustical measurements:

- The analysis of the music of Giacinto Scelsi in terms of G factor values and room volume.
- Architectural designs based on values taken from musical scores. This topic suggests the reverse approach offered in this study, where the musical score is strictly considered as an architectural plan.
- Analysis of Debussy’s *Preludes* utilizing the “system of weights”.
- Algorithmic composition around a given centroid value. Elaboration of a system that can generate music weighted around room formants.
- Centroid and music cognition. Research about the aural perception of centers of weight in music. Do we perceive the centroid value as the gravity center of complexes constructed around it?
- Inclusion of the meta-instrument in the daily practice for instrumentalists. Study of the necessary acoustical qualities for a reliable practice room.
- Design of “impossible” acoustical spaces in CATT acoustics in order to capture their acoustical properties and translate them into music.
- Use of the system of weights as a tool to analyze works of the so-called total serialism.
- Similarities and differences between the proposed model and the techniques proposed by the total serialism.

APPENDIX A

APPLICATION OF THE MODEL IN A MUSIC COMPOSITION – *COLORS* FOR ORCHESTRA

“Colors”

(for Orchestra)

Jorge Variego

VIII – 2010

Duration: 9’ 30’’(app.)

Instrumentation

Piccolo
Flute I/ Piccolo
Flute II /Alto Flute / Piccolo
2 Oboes
English Horn
2 Bassoons
Contrabassoon
Eb Clarinet
2 Bb Clarinets / Prepared clarinets in Bb/A
Bass Clarinet
4 French horns in F
3 Trumpets in C
2 Trombones
1 Bass Trombone
1 Tuba
Timpani
3 Percussionists:

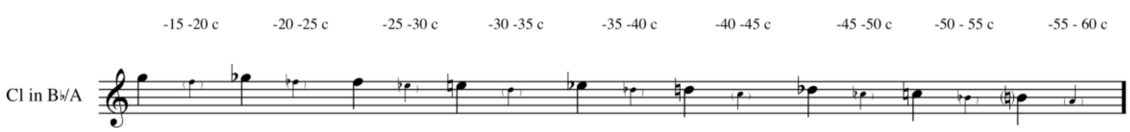
- Vibraphone
- 3 Tom – toms
- Bass drum
- Suspended cymbal
- Marimba

Harp
Piano / Celesta
Strings

<u>Note:</u>

To prepare the clarinet in Bb/A the players must assembly the instrument with the upper joint (including the barrel and the mouthpiece) of the Bb clarinet, and the bottom joint (including the bell) of the A clarinet. This preparation generates different pitches in certain registers of the instrument. The notes omitted in the chart are not affected.
The written note is followed by the concert pitch (between parenthesis) with its particular pitch.
The numbers imply ranges (i.e. between - 15 and - 20 cents, etc.)

C = cents

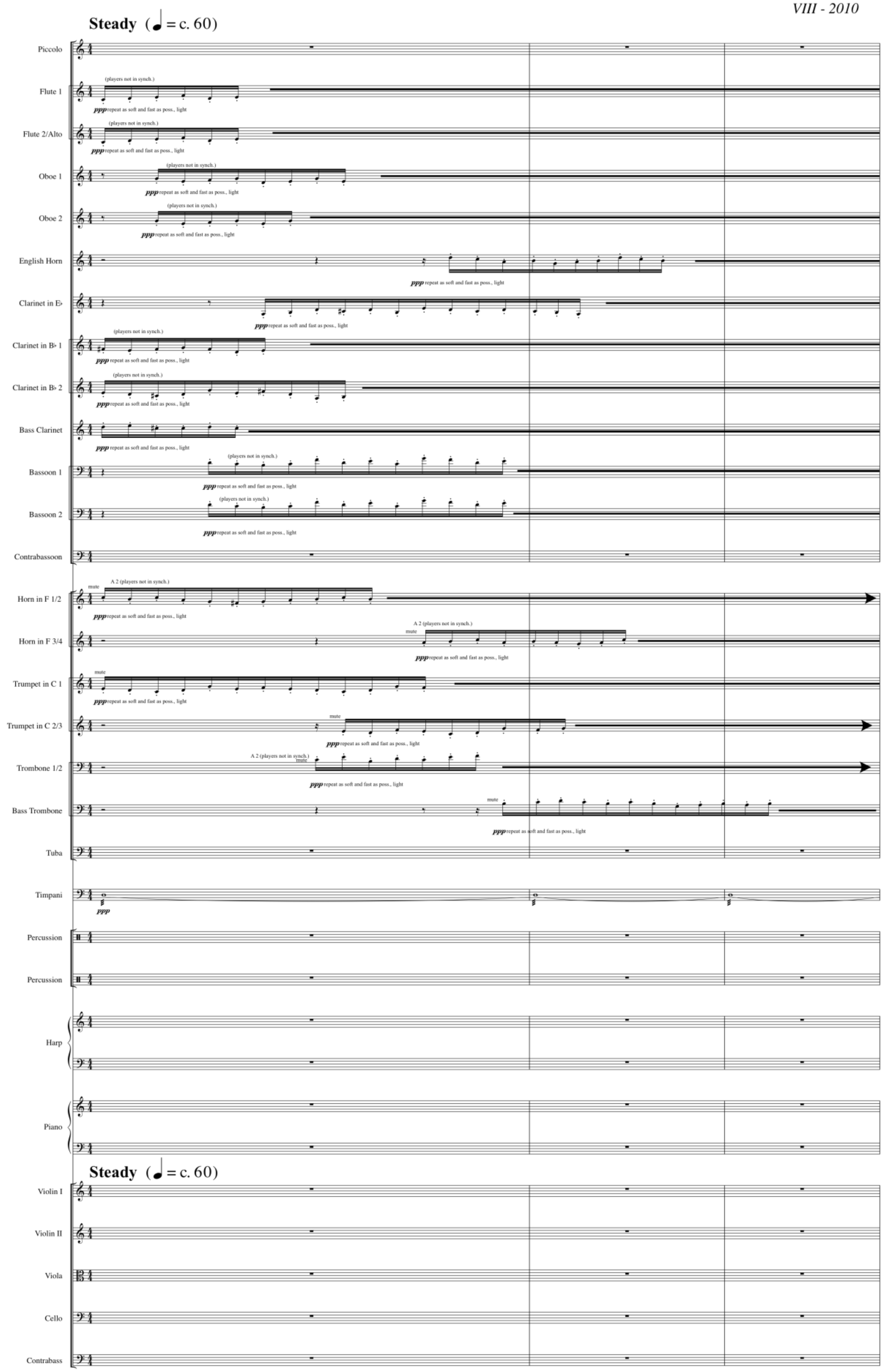


Transposed score

Colors

Jorge Variego

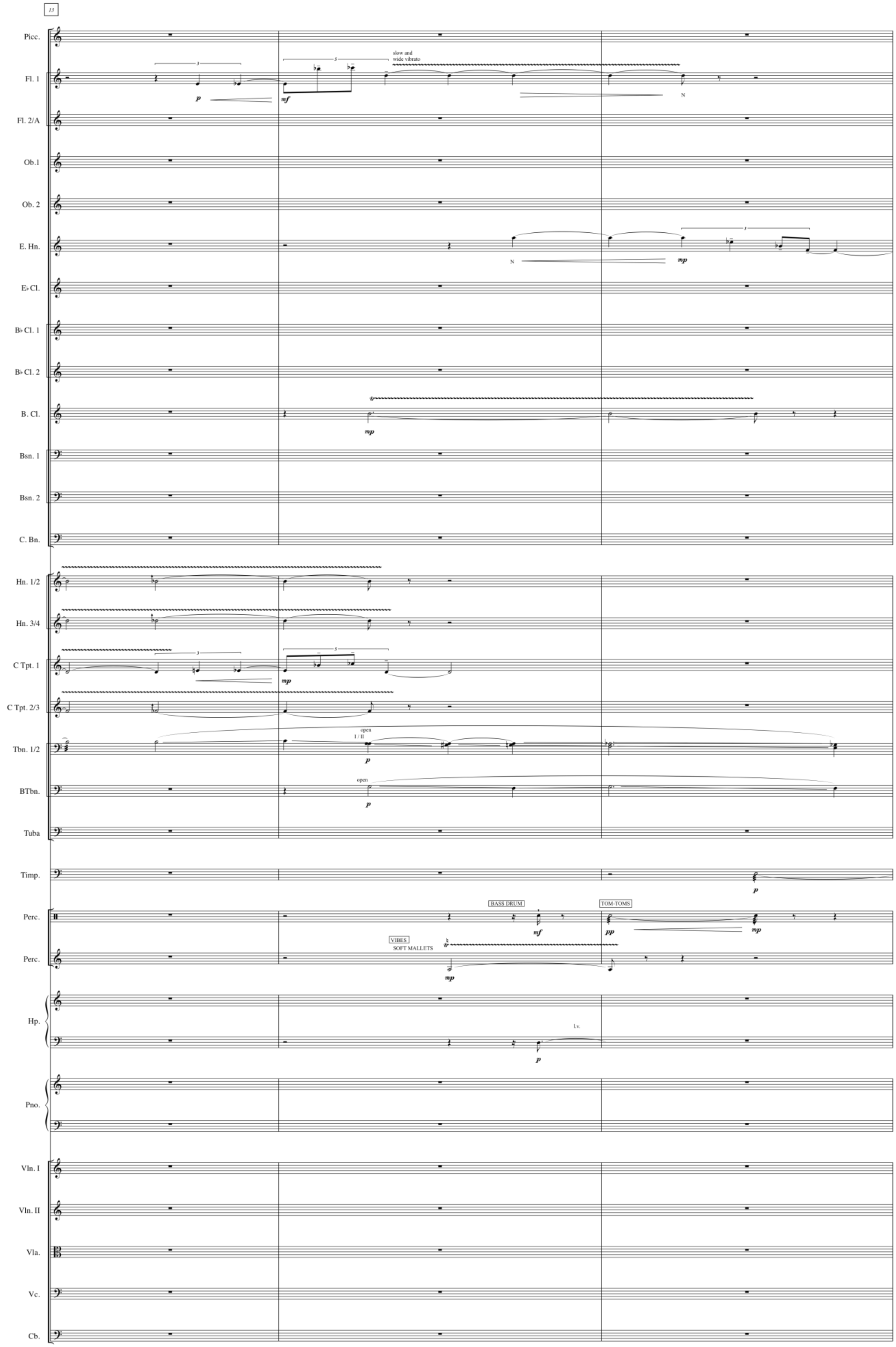
VIII - 2010




A
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭Cl.
B♭Cl. 1
B♭Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
sim.


7
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
mf
ppp
TOM-TOMS
ppp repeat as soft and fast as poss., light
mfppp
do not l.v.
f


10
B
Picc.
Fl. 1
Fl. 2/A
mp
Ob.1
Ob. 2
E. Hn.
mp espress.
pp sub.
E♭ Cl.
B♭ Cl. 1
N
mf
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
I mute
II open
Hn. 3/4
III mute
IV open
C Tpt. 1
mute
C Tpt. 2/3
II mute
III open
pp
Tbn. 1/2
1st only open
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
do not l.v.
f
Cb.

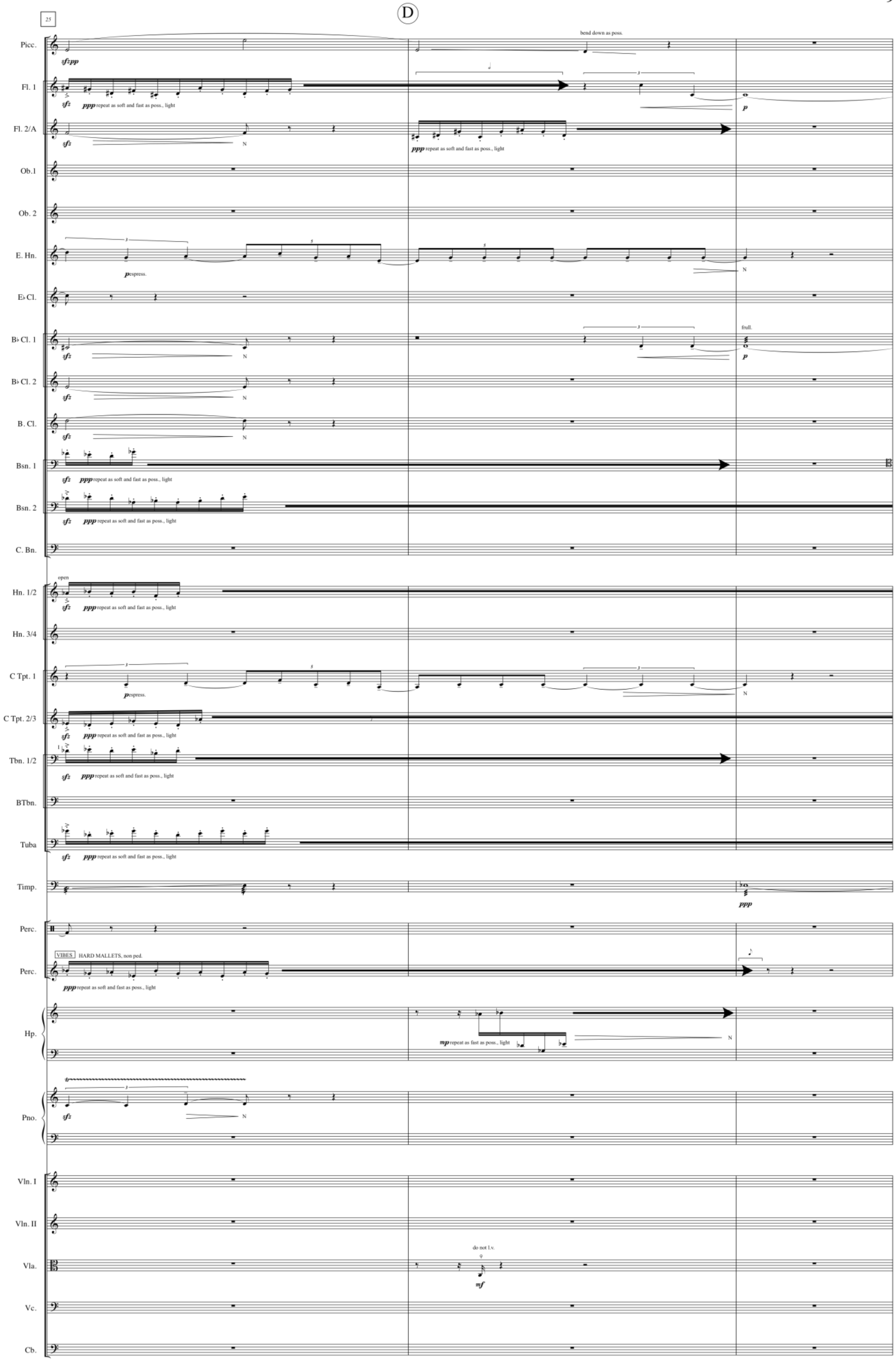

13
Picc.
Fl. 1
slow and
wide vibrato
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
open
I / II
BTbn.
open
Tuba
Timp.
Perc.
BASS DRUM
TOM-TOMS
VIBES
SOFT MALLETS
Perc.
Hp.
l.v.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.

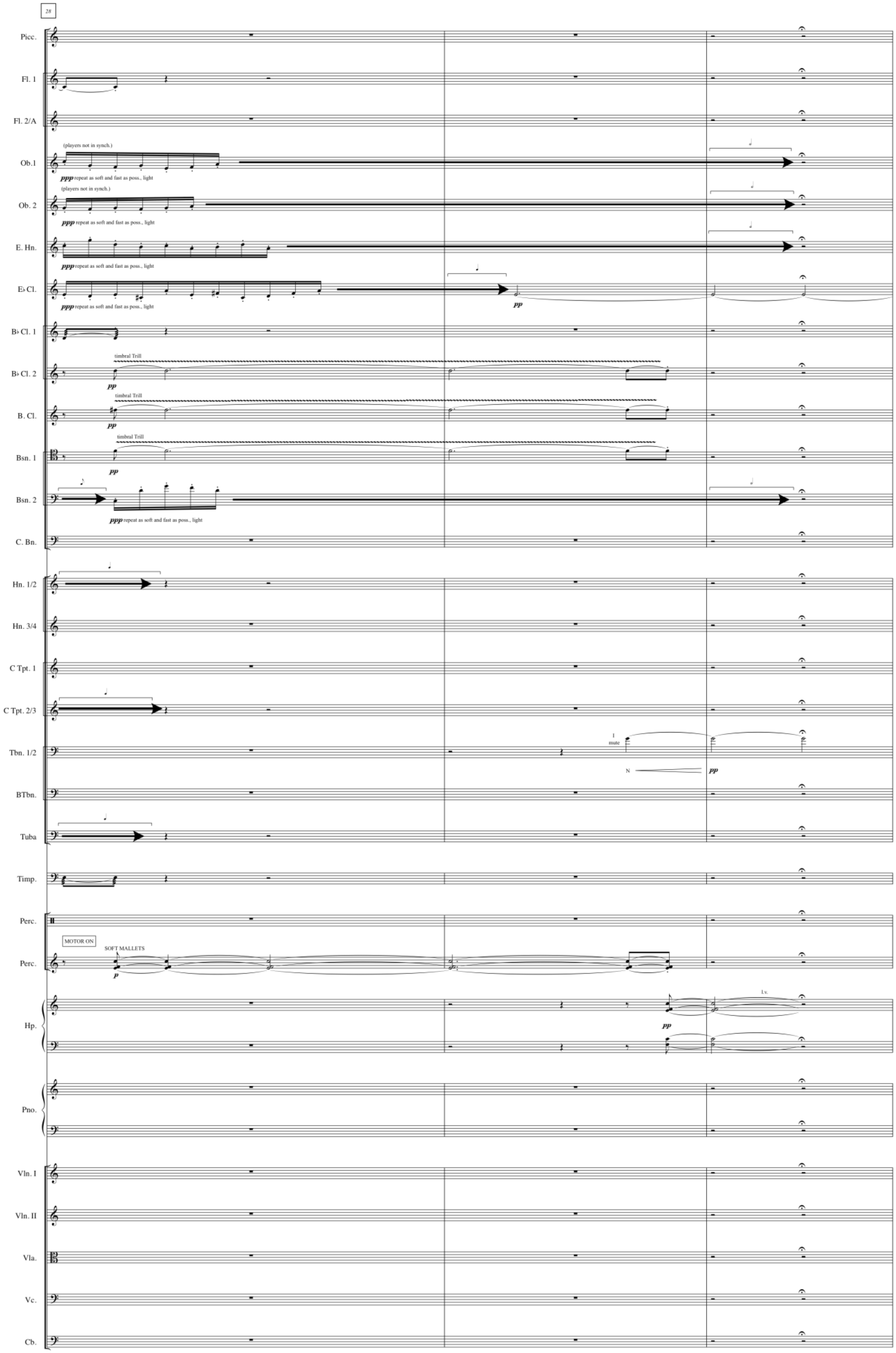

C
16
slow and wide vibrato
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
timbral Trill
E♭ Cl.
B♭ Cl. 1
produce sound with the mouthpiece and barrel only
vary the intonation by covering the hole with the hand
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
repeat as soft and fast as poss., light
A 2 (players not in synch.)
bouchee
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
(almost legato)
Timp.
Perc.
w/ bow
Hp.
l.v.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.

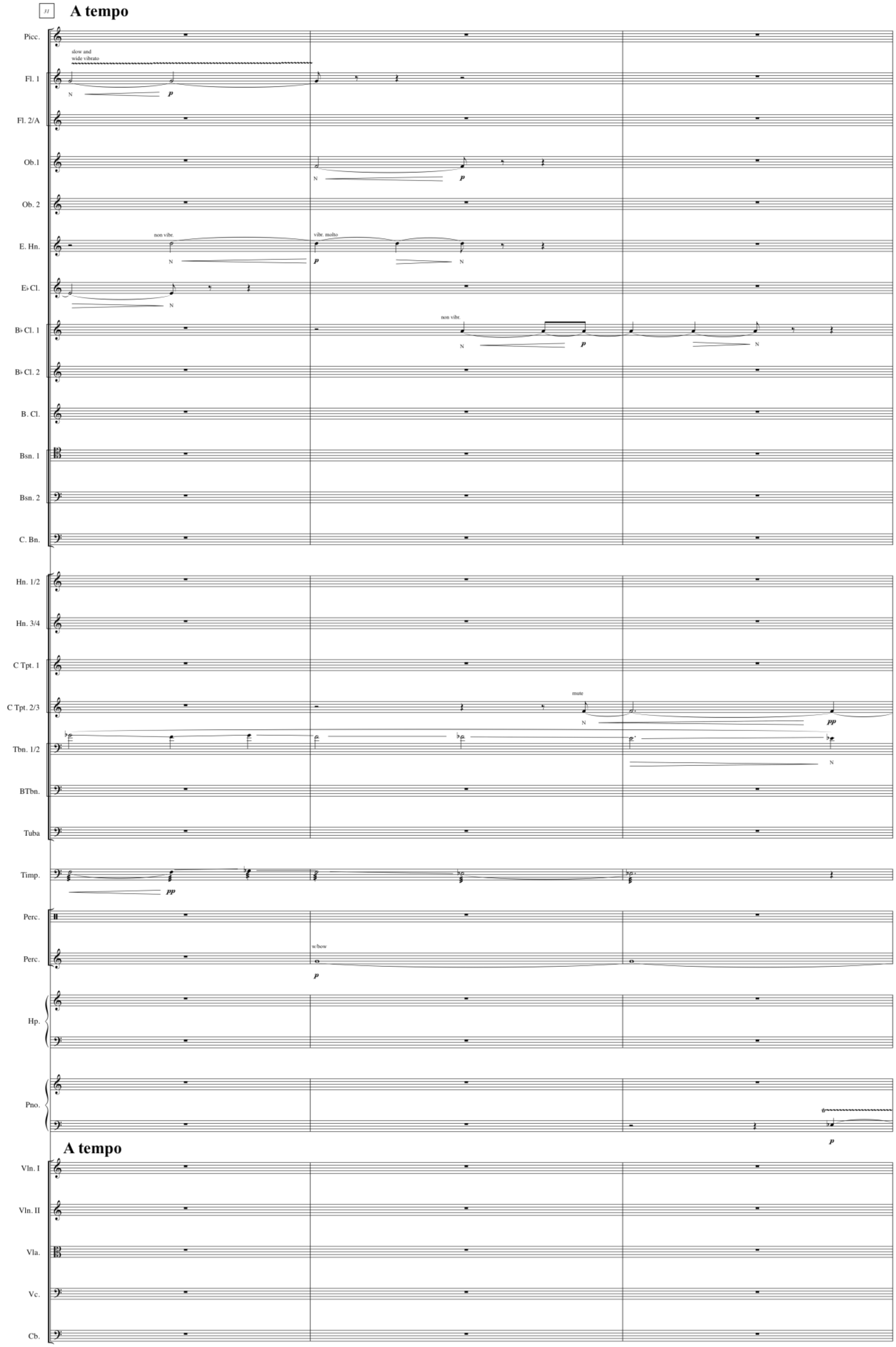

19
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
timbral Trill
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
mute
mfppp
C Tpt. 1
C Tpt. 2/3
ppp
Tbn. 1/2
BTbn.
Tuba
Timp.
TOM-TOMS
SOFT MALLETS
Perc.
Perc.
Hp.
Pno.
ppp repeat as soft and fast as poss., light
Vln. I
Vln. II
Vla.
Vc.
Cb.


19
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
timbral Trill
mute
TOM-TOMS
SOFT MALLETS
ppp repeat as soft and fast as poss., light


22
Picc.
Fl. 1
slow and wide vibrato
Fl. 2/A
timbral Trill
Ob.1
Ob. 2
E. Hn.
E♭Cl.
non vibr.
B♭Cl. 1
B♭Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
mute
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.


25
D
Picc.
sfzpp
bend down as poss.
Fl. 1
sfz
ppp repeat as soft and fast as poss., light
p
Fl. 2/A
sfz
N
ppp repeat as soft and fast as poss., light
Ob.1
Ob. 2
E. Hn.
p espress.
N
E♭ Cl.
B♭ Cl. 1
sfz
N
frull.
p
B♭ Cl. 2
sfz
N
B. Cl.
sfz
N
Bsn. 1
sfz
ppp repeat as soft and fast as poss., light
Bsn. 2
sfz
ppp repeat as soft and fast as poss., light
C. Bn.
open
Hn. 1/2
sfz
ppp repeat as soft and fast as poss., light
Hn. 3/4
C Tpt. 1
p espress.
N
C Tpt. 2/3
sfz
ppp repeat as soft and fast as poss., light
Tbn. 1/2
sfz
ppp repeat as soft and fast as poss., light
BTbn.
Tuba
sfz
ppp repeat as soft and fast as poss., light
Timp.
ppp
Perc.
VIBES
HARD MALLETS, non ped.
Perc.
ppp repeat as soft and fast as poss., light
Hp.
mp repeat as fast as poss., light
N
Pno.
sfz
N
Vln. I
Vln. II
do not l.v.
Vla.
mf
Vc.
Cb.


28
Picc.
Fl. 1
Fl. 2/A
Ob.1
(players not in synch.)
ppp repeat as soft and fast as poss., light
Ob. 2
(players not in synch.)
ppp repeat as soft and fast as poss., light
E. Hn.
ppp repeat as soft and fast as poss., light
E♭ Cl.
ppp repeat as soft and fast as poss., light
pp
B♭ Cl. 1
B♭ Cl. 2
timbral Trill
pp
B. Cl.
timbral Trill
pp
Bsn. 1
timbral Trill
pp
Bsn. 2
ppp repeat as soft and fast as poss., light
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
I
mute
N
pp
BTbn.
Tuba
Timp.
Perc.
MOTOR ON
SOFT MALLETS
p
Perc.
Hp.
pp
l.v.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.

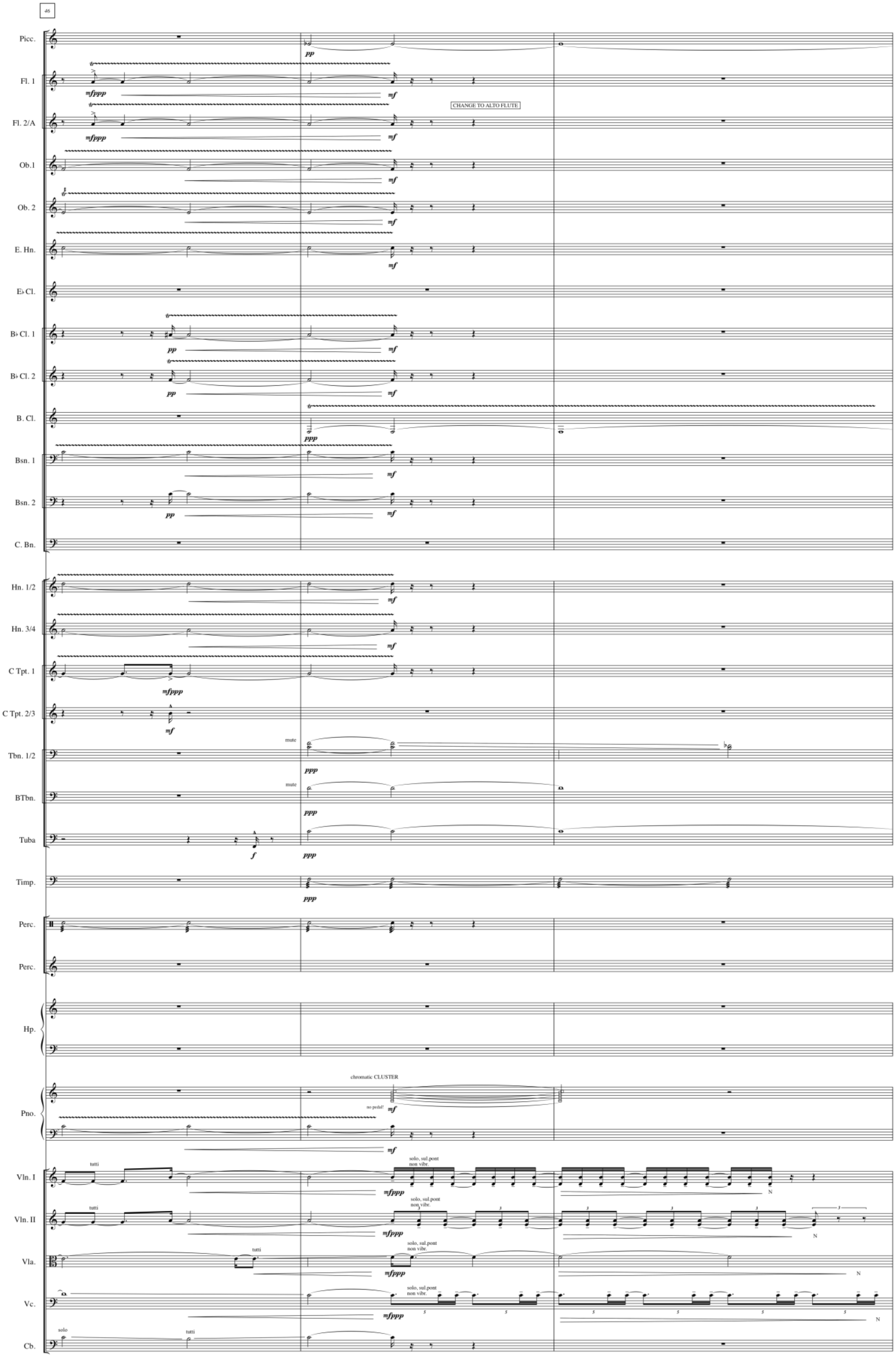

A tempo
Picc.
slow and
wide vibrato
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
non vibr.
vibr. molto
E. Hn.
E♭ Cl.
non vibr.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
mute
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
w/bow
Perc.
Hp.
Pno.
A tempo
Vln. I
Vln. II
Vla.
Vc.
Cb.

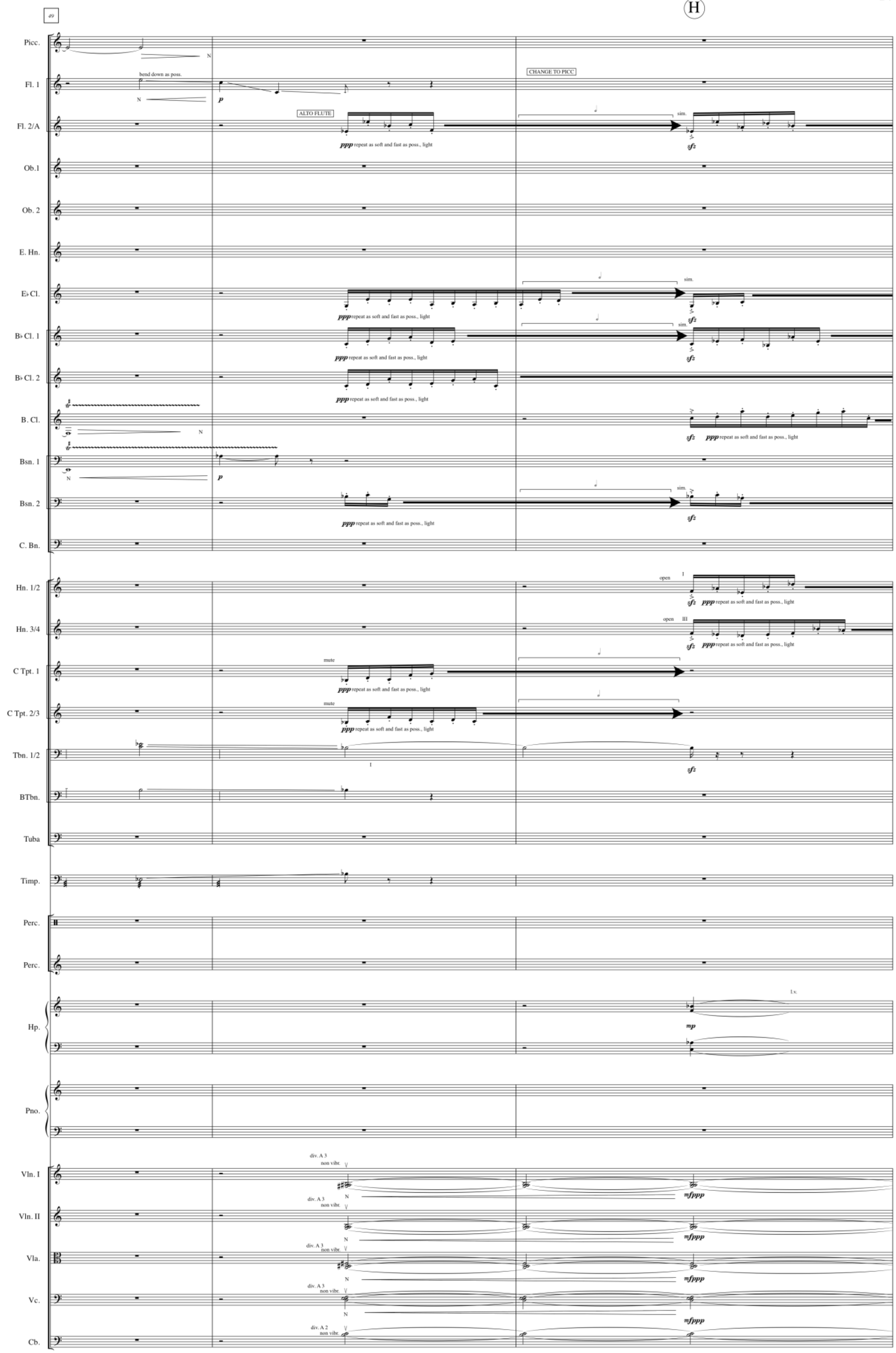

34
E
A tempo
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭Cl.
B♭Cl. 1
B♭Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
non vibr.
N
pp
ppp repeat as soft and fast as poss., light
ppp espr.
A 2 (players not in synch.)
mute
open
GONG
ppp
SOFT MALLETS
A tempo


37
F
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
sim.
pp
mfppp repeat as soft and fast as poss., light
non cresc.
N
mf
TOM-TOMS
ppp
l.v.
do not l.v.


40
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
ppp repeat as soft and fast as poss., light
sim.
(players not in synch.)
mute
MOTOR ON
w/bow
SLOW
FAST

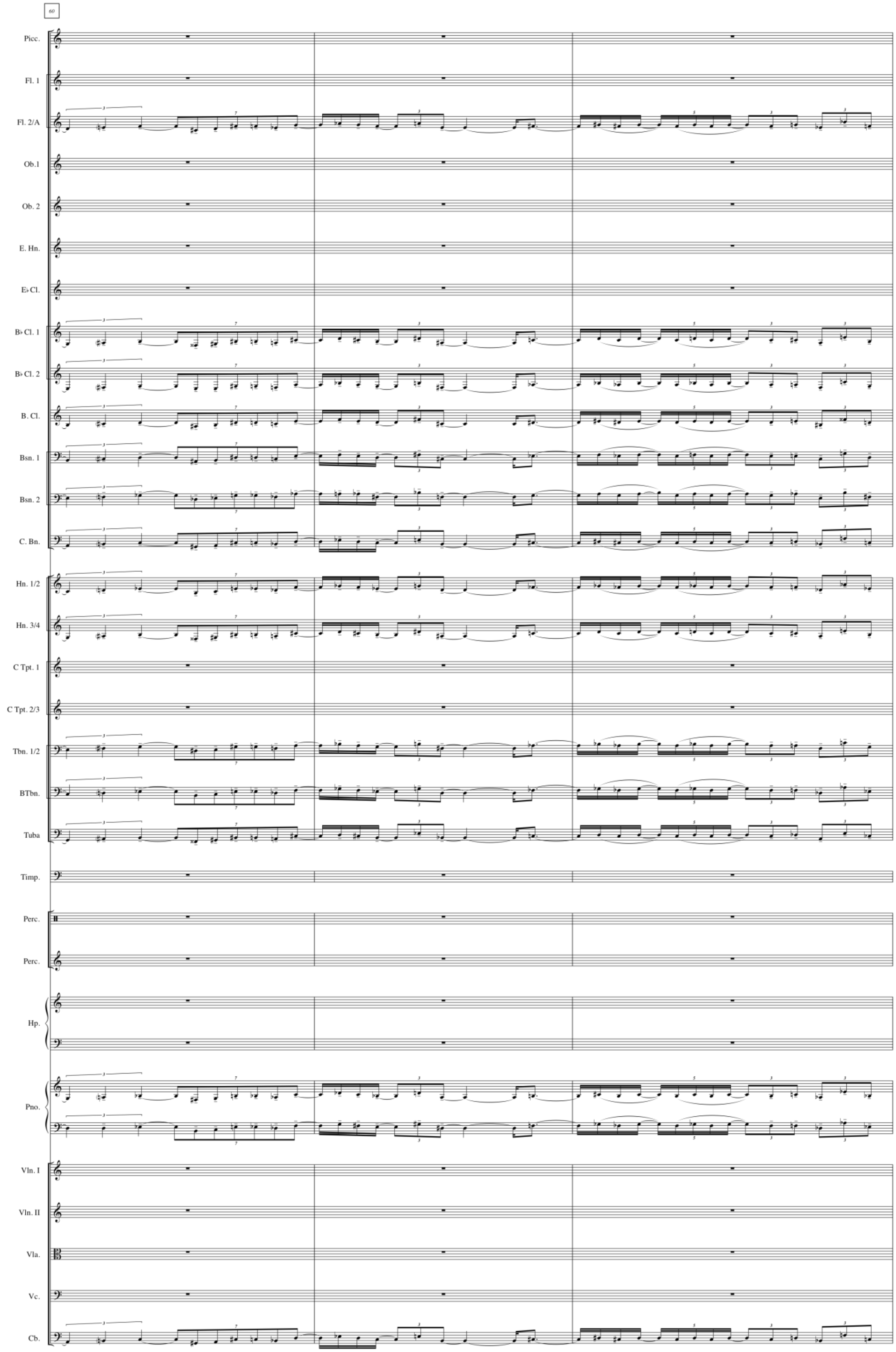

43
G
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
sim.
ppp
mfppp
A 2
mute
mf
TOM-TOMS
SLOW
tutti
solo
do not l.v.

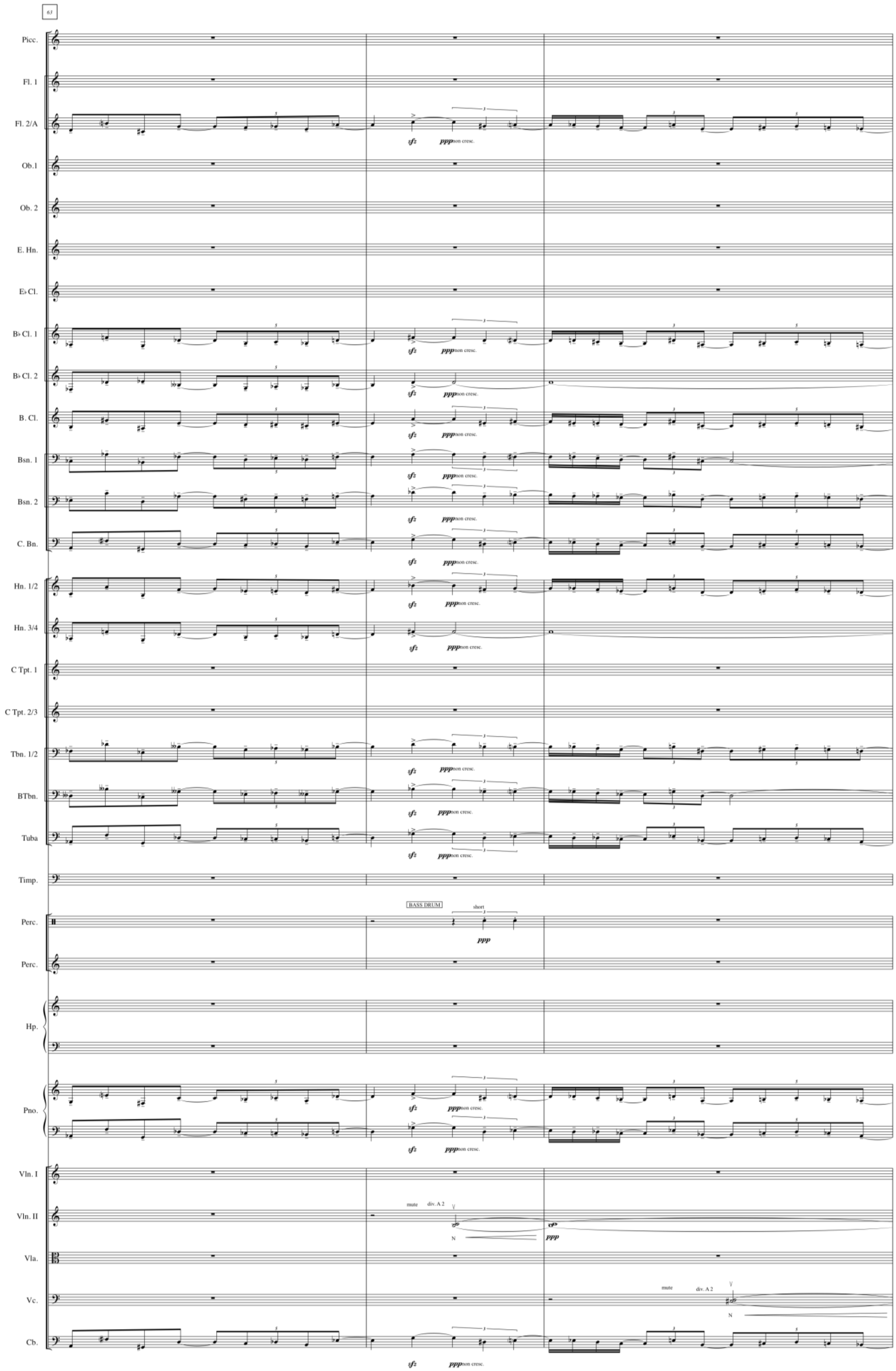

46
Picc.
Fl. 1
Fl. 2/A
CHANGE TO ALTO FLUTE
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
mute
BTbn.
mute
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
chromatic CLUSTER
no pedal!
Vln. I
tutti
solo, sul.pont
non vibr.
Vln. II
tutti
solo, sul.pont
non vibr.
Vla.
tutti
solo, sul.pont
non vibr.
Vc.
solo, sul.pont
non vibr.
Cb.
solo
tutti

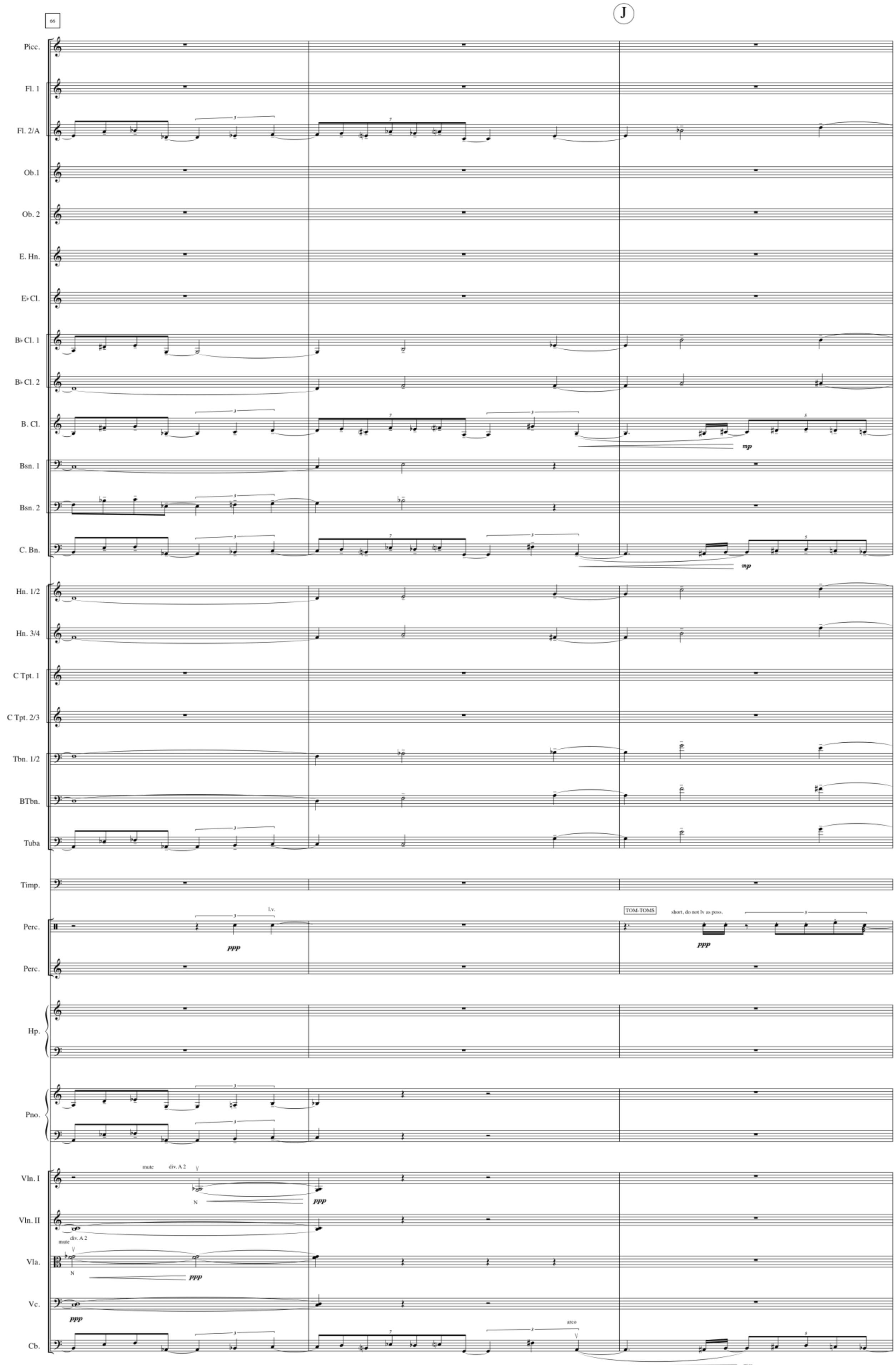

49
H
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
bend down as poss.
CHANGE TO PICC
ALTO FLUTE
ppp repeat as soft and fast as poss., light
sim.
sfz
open
mute
l.v.
div. A 3
non vibr.
div. A 2
mfppp


52
Picc.
Fl. 1
Fl. 2/A
slow and wide vibrato
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
pp non cresc.
Bsn. 1
pp non cresc.
Bsn. 2
C. Bn.
Hn. 1/2
mute I
II open
Hn. 3/4
mute III
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
pp non cresc.
BTbn.
mute
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
chromatic CLUSTER
no pedal!
Vln. I
vibr. molto
solo non vibr.
tutti
Vln. II
Vla.
Vc.
Cb.


I
56
rit.
A tempo
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
II open
IV open
mute
non cresc.
div. A 3
solo
pizz.


60
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭Cl.
B♭Cl. 1
B♭Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.


63
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
sfz
ppp non cresc.
BASS DRUM
short
ppp
mute
div. A 2
N
ppp


66
J
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
mp
l.v.
ppp
TOM-TOMS
short, do not lv as poss.
mute
div. A 2
N
arco

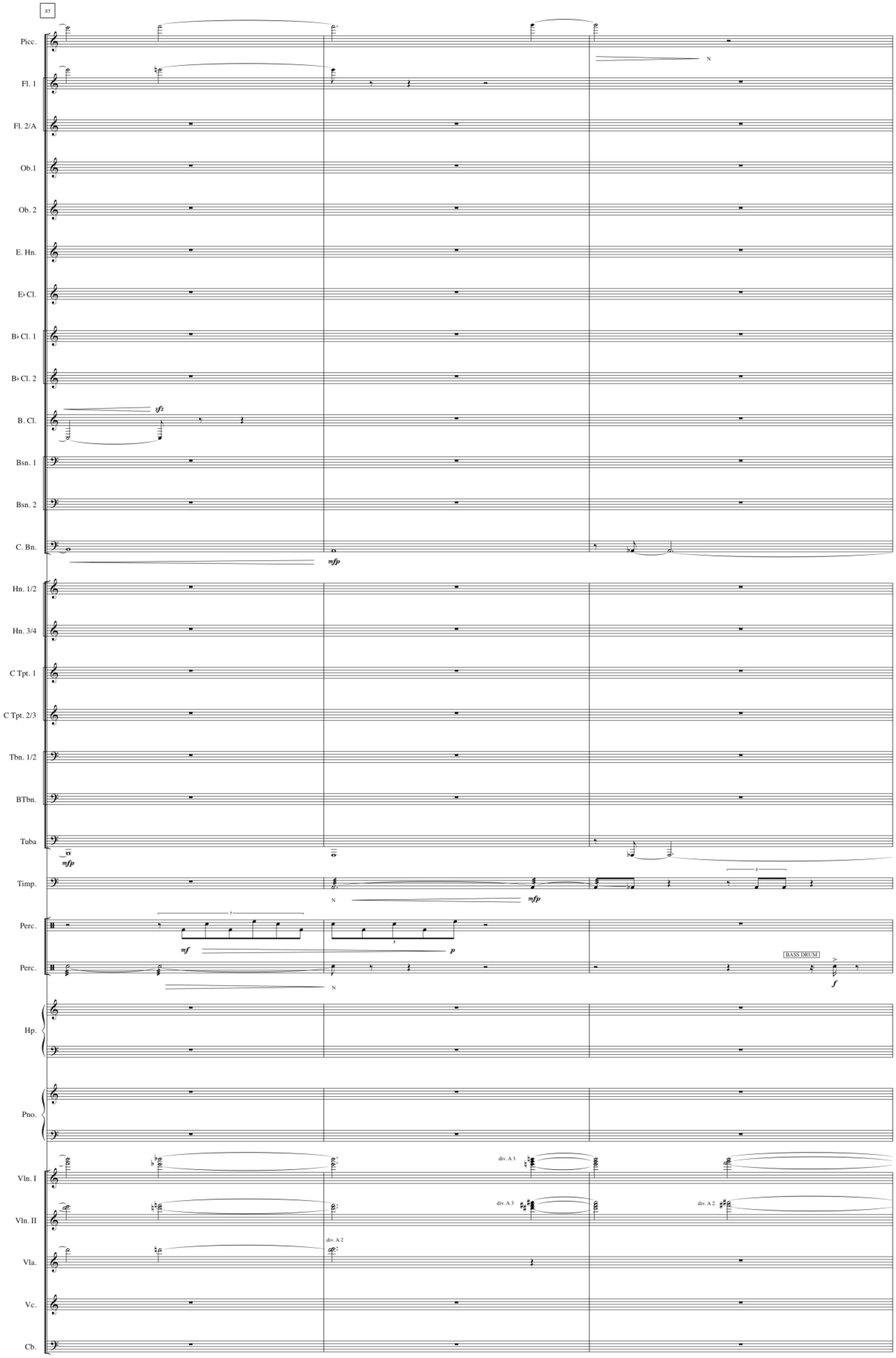

69
Picc.
Fl. 1
PICC.
non vibr.
N
ppp non cresc.
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
non vibr.
N
ppp non cresc.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
mute
p
C Tpt. 2/3
mute
p
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
BASS DRUM
short, do not l.v.
ppp
Hp.
Pno.
Vln. I
div. A 2
div. A 3
ppp
Vln. II
div. A 2
div. A 3
ppp
Vla.
div. A 2
ppp
Vc.
div. A 2
ppp
Cb.

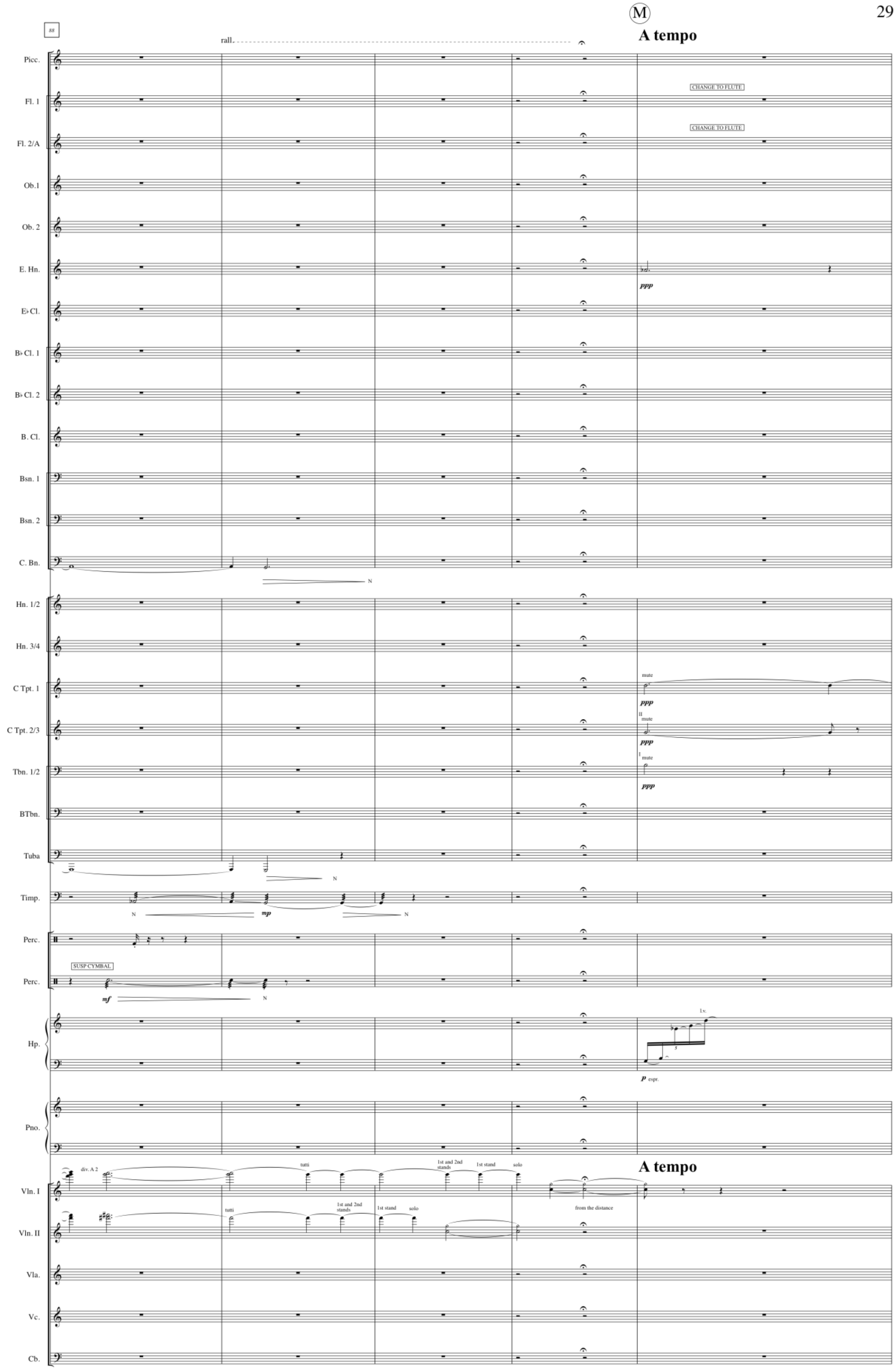

72
K
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
non vibr.
fppp
ppp
CHANGE TO PICC
mf
p
CELESTA
CHANGE TO PIANO
N

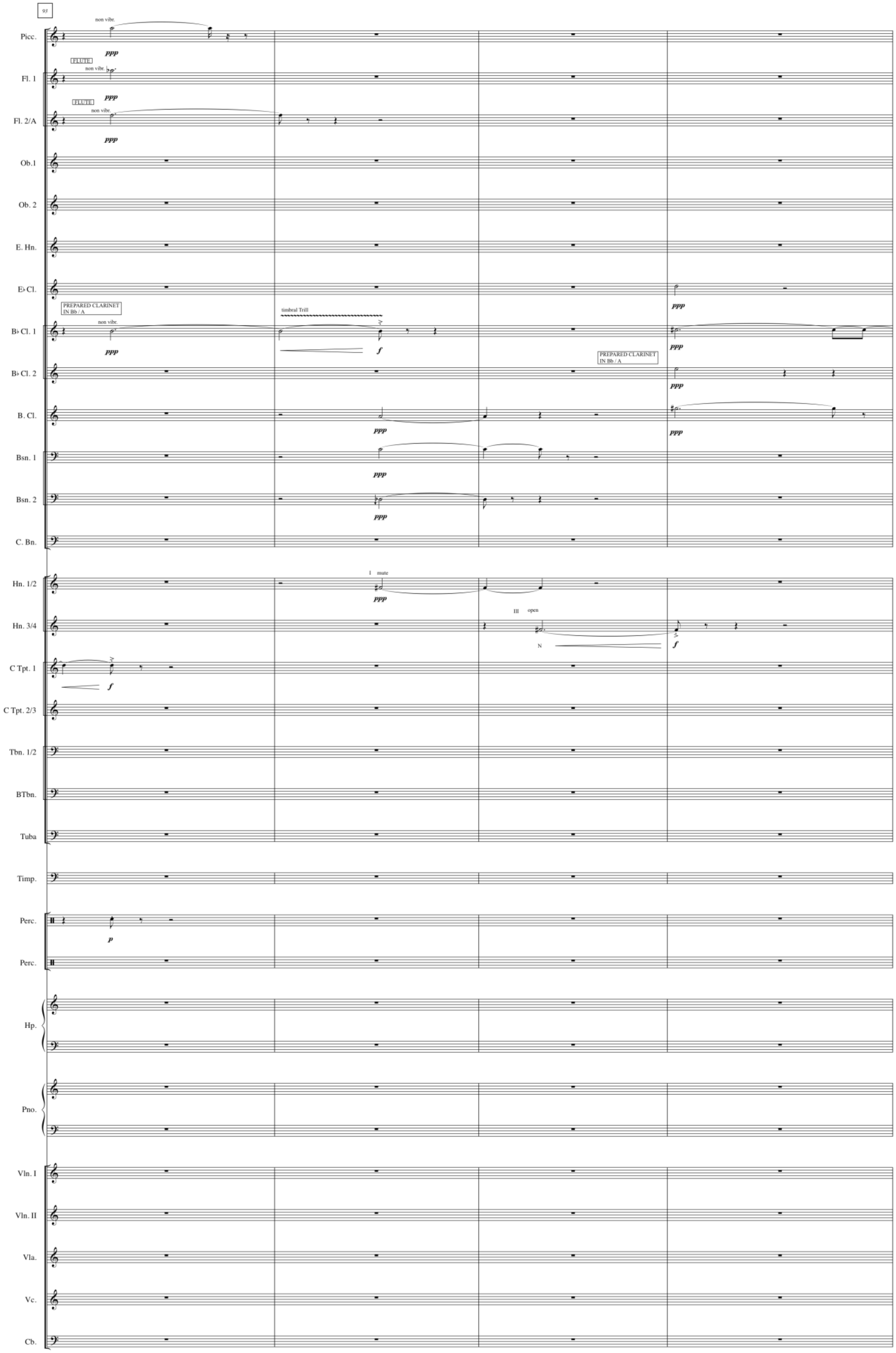

75
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
PIANO
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
ppp non cresc., as poss.
N
ppp
fp
l.v.
p
vibr. molto
div. A 3
pp

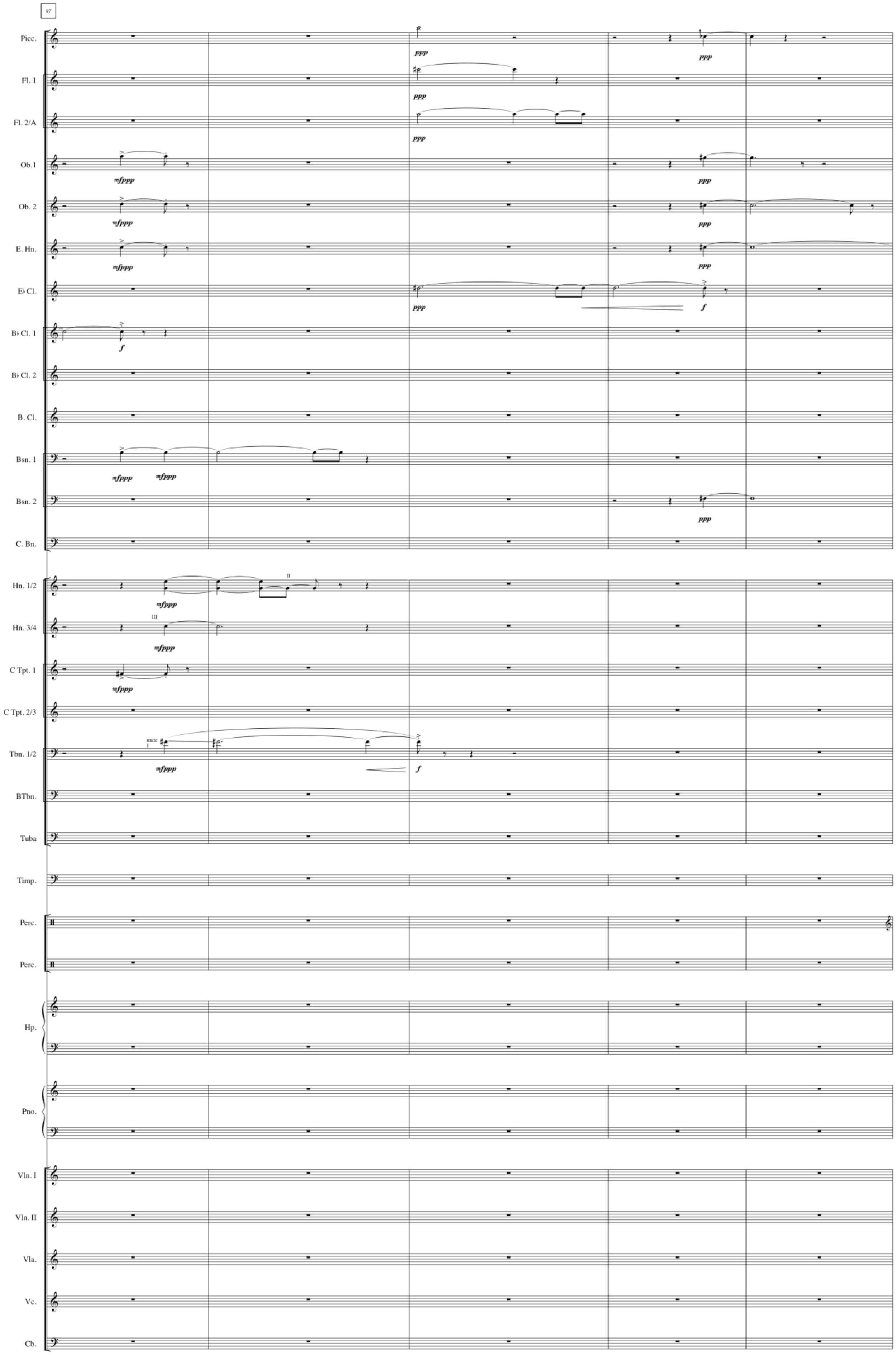

78
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭Cl.
B♭Cl. 1
B♭Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
fp
p
mp
div. A 2
N


81
L
slow and wide vibrato
non vibr.
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
CHANGE TO PREPARED CLARINETIN Bb / A
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
nat.
GONG
l.v.
BASS DRUM
do not l.v.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.


85
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭Cl.
B♭Cl. 1
B♭Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
sfz
mfp
mfp
mfp
mf
p
N
N
N
BASS DRUM
f
div. A 3
div. A 3
div. A 2
div. A 2


M
A tempo
88
rall.
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
CHANGE TO FLUTE
CHANGE TO FLUTE
ppp
N
mute
ppp
mute
ppp
mute
ppp
N
N
mp
N
SUSP CYMBAL
mf
N
l.v.
p espr.
div. A 2
tutti
1st and 2nd stands
1st stand
solo
A tempo
tutti
1st and 2nd stands
1st stand
solo
from the distance

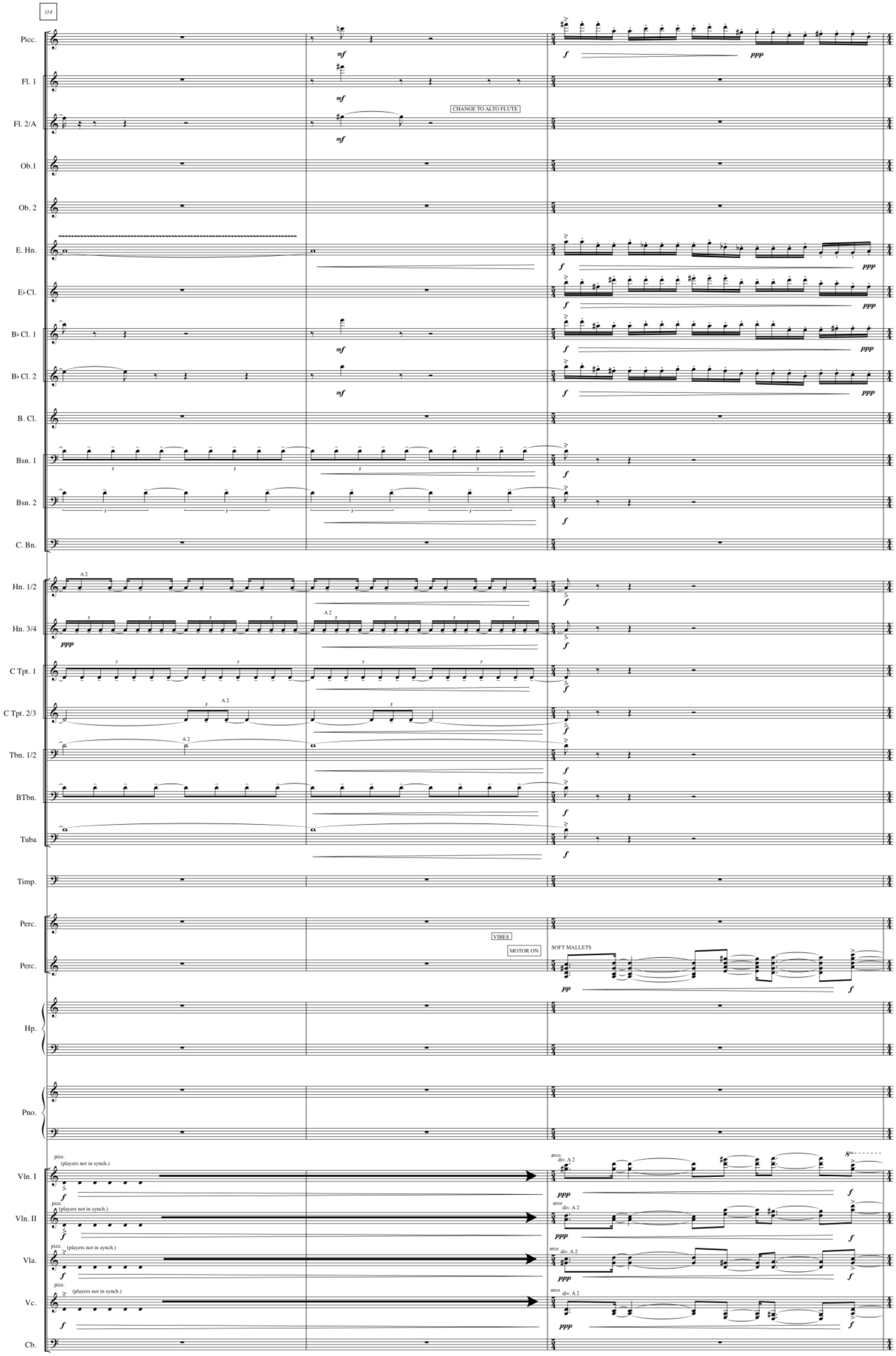

Picc.
non vibr.
FLUTE
Fl. 1
non vibr.
FLUTE
Fl. 2/A
non vibr.
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
PREPARED CLARINET IN Bb / A
non vibr.
timbral Trill
B♭ Cl. 1
PREPARED CLARINET IN Bb / A
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
I mute
Hn. 1/2
III open
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.


97
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭Cl.
B♭Cl. 1
B♭Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
ppp
mfppp
f
mute


102
N
(always)
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
slow and wide vibrato
gradually increasing vibrato
mute
(end abruptly without accent)
VIBES
SOFT MALLETS
MOTOR ON
FAST
(always)

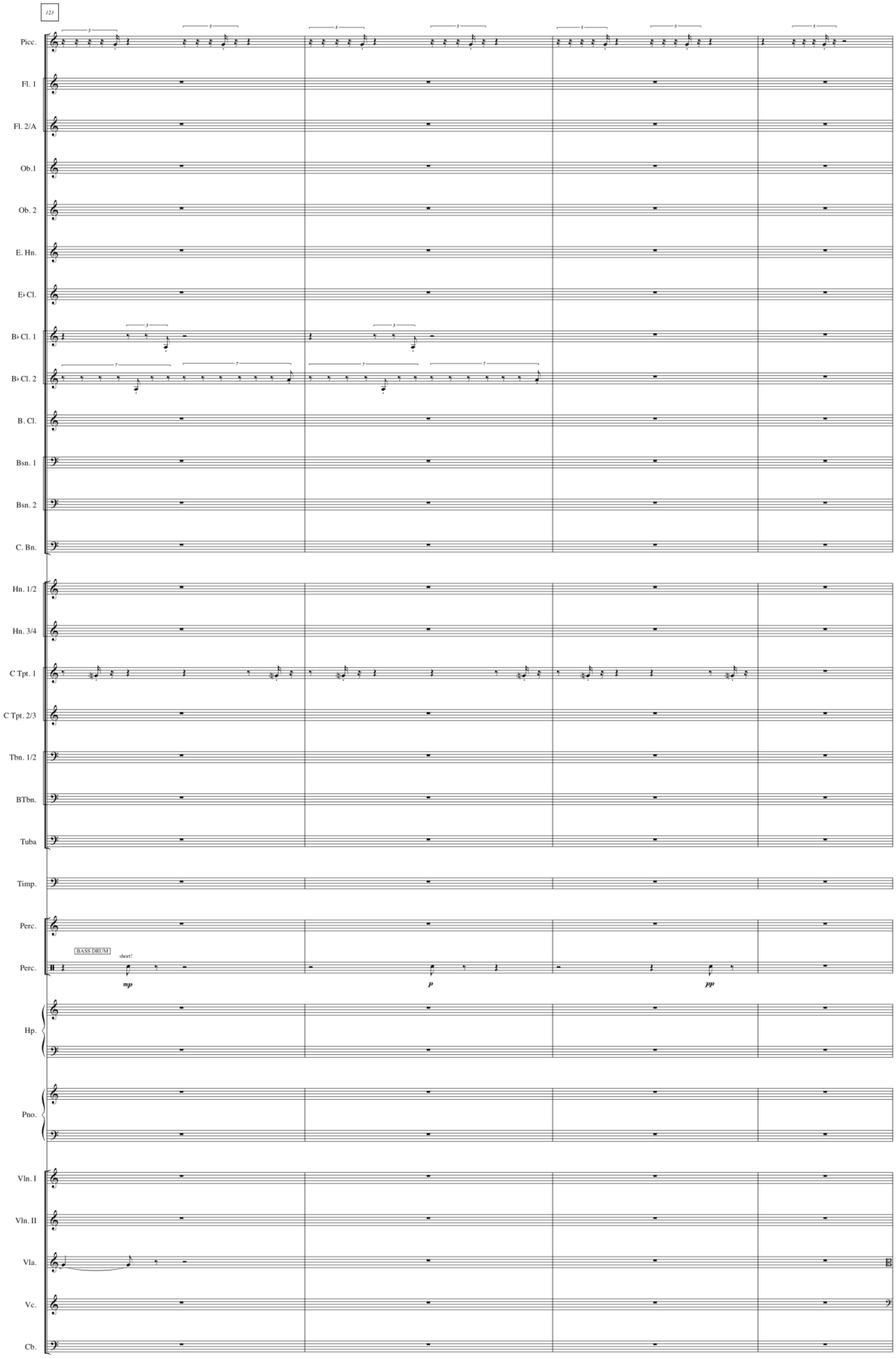

106
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭Cl.
B♭Cl. 1
B♭Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
ppp
f
1 mute

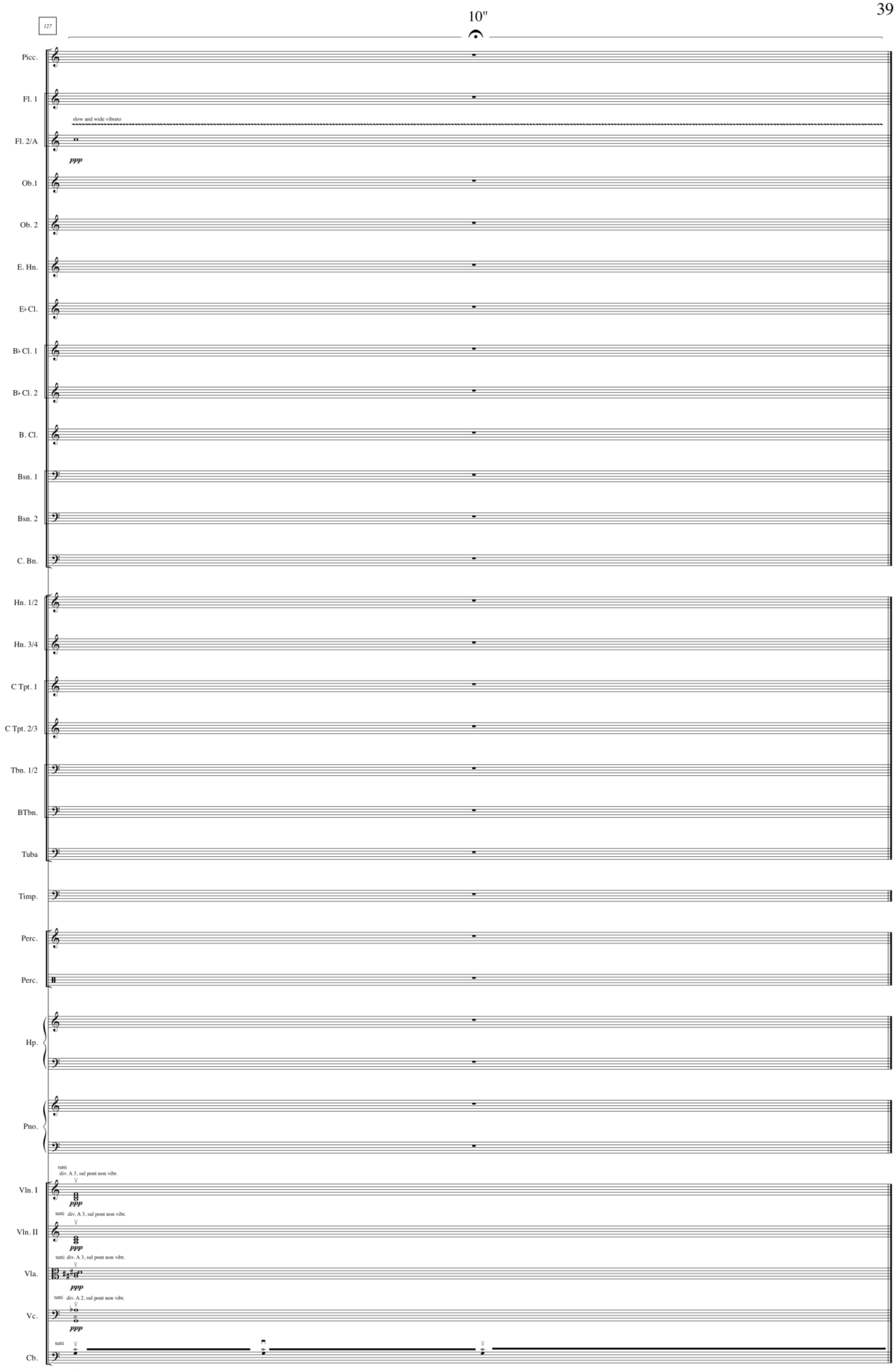

110
O
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭Cl.
B♭Cl. 1
B♭Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.
timbral Trill
mute I
mute
II mute
II open
mute off
sul pont, non vibr.
SUL III
behind the bridge, sul pont with pressure, over the wrapping of the string
SUL II
behind the bridge, sul pont with pressure, over the wrapping of the string


114
Picc.
Fl. 1
Fl. 2/A
CHANGE TO ALTO FLUTE
Ob.1
Ob. 2
E. Hn.
E♭Cl.
B♭Cl. 1
B♭Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
A 2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
VIBES
MOTOR ON
SOFT MALLETS
Perc.
Hp.
Pno.
pizz.
(players not in synch.)
arco
div. A 2
Vln. I
Vln. II
Vla.
Vc.
Cb.


117
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
mute
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
l.v.
Hp.
do not l.v.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.


120
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
Vln. I
solo, sul pont, DIV a 2
non cresc.
solo
nat.
mp
ppp
Vln. II
solo, sul pont, DIV a 2
non cresc.
nat.
Vla.
solo, sul pont, DIV a 2
non cresc.
nat.
Vc.
solo, sul pont, DIV a 2
non cresc.
nat.
Cb.


123
Picc.
Fl. 1
Fl. 2/A
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
BASS DRUM
short!
Perc.
mp
p
pp
Hp.
Pno.
Vln. I
Vln. II
Vla.
Vc.
Cb.


127
10"
Picc.
Fl. 1
slow and wide vibrato
Fl. 2/A
ppp
Ob.1
Ob. 2
E. Hn.
E♭ Cl.
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
C. Bn.
Hn. 1/2
Hn. 3/4
C Tpt. 1
C Tpt. 2/3
Tbn. 1/2
BTbn.
Tuba
Timp.
Perc.
Perc.
Hp.
Pno.
tutti
div. A 3, sul pont non vibr.
Vln. I
ppp
tutti div. A 3, sul pont non vibr.
Vln. II
ppp
tutti div. A 3, sul pont non vibr.
Vla.
ppp
tutti div. A 2, sul pont non vibr.
Vc.
ppp
tutti
Cb.
ppp

APPENDIX B
APPLICATION OF THE MODEL IN A MUSIC COMPOSITION – *ETUDE FOR STRING QUARTET*

Etude

(for string quartet; an application of the compositional model based on the acoustical parameters from the Baughman Center)


2
Vln. I
Vln. II
Vla.
Vc.
sul pont.
pizz.
ord.
arco
ord.
ppp
p
arco
non vibr.
SUL II
nat.
pp
mf
mp p

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BIOGRAPHICAL SKETCH

Jorge Elias Variego is a clarinetist and composer born in Rosario, Argentina, in 1975. He holds a bachelor's degree from the Universidad Nacional de Rosario and a master's degree from Carnegie Mellon University with double major in composition and clarinet performance. He received his PhD from the University of Florida in the spring of 2011.

He has performed as soloist with the most renowned orchestras in Argentina and his works have been performed throughout the world. Among other distinctions, he has been awarded First prize in the "Carlos Guastavino" composition contest, First Prize in the "Jorge Peña Hen" composition contest for youth orchestras, Premio Tribunas de Música Argentina 2007, ASCAP Award, Society of Composers Students Commission Regional Competition. He has received prestigious scholarships from Fondo Nacional de las Artes (Argentina), Antorchas Foundation (Argentina), Fulbright Commission (Argentina), Carnegie Mellon University (USA), Universidad de Santiago de Compostela (Spain), Pi Kappa Lambda Honors Music Society, among others. He has been a resident artist at the Pittsburgh Center for the Arts for the last five years