Audio-Visual Frameworks for Design Process Representation

by

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Licenciatura em Arquitectura
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Submitted to the Department of Architecture
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at the

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Abstract:

The design process is based on a recursive and iterative feedback between a designer's ideas and their physical representation. In most practices, this feedback takes place upon one single medium, which endows the designer with one single view on his ideas. However, having several views can contribute for a deeper and more informed critique of the physical representation of those ideas; ultimately it can lead to a better final product.
In the first part of this study, the use of audio-visual interfaces as tools for representing the design process is proposed. The idea is to understand, through simulation, what beneficial effects a process based on multiple feedbacks can potentially have on the actual design. As such, five frameworks mapping graphics to sound were designed and implemented computationally.
Although the referred interfaces were in fact designed as a means to support a claim, they mainly stand out as independent objects that carry a significance of their own. The second part of this research explores the relevance of these objects as media that yield new forms of audio-visual design, engage the user in design thinking, and support design education.

Thesis Supervisor: William L. Porter

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1. Introduction

1.1. Overview

As new technologies become more relevant in design activities, the design process needs to be constantly rethought and updated in order to lead to meaningful results. As such, the study of the design process is a growing field that has gained weight over the last decades in several universities. At MIT, research made in the Design and Computation group, within the Department of Architecture, seeks to reach a thorough understanding of the design process. The idea is to find where computation stands or may stand in architectural design.

The study of the design process can be approached in several ways. Simulation is one; it consists of creating an abstraction out of a real-world problem and reducing its complexity, i.e. reducing the number of existing variables in the original problem. The idea is to keep the variables that are of interest for studying the problem at hand. Once one is before the simplified problem, the search for an optimal solution is also made simpler, and, after a solution has been found, it may be placed in the context of the original problem. However, when a problem is simplified, an error margin has to be taken into consideration. According to that margin, the validity of the results, or at least the validity of the part of the results that are significant within the problem's range, might be affected.

Simulation is used in every field of knowledge. In architecture, it is commonly used in models and scaled drawings, and the margin of error is reduced as the scale of the simulations increases. In the case of design inquiry, simulation may be used in several ways. One way is to metaphorically represent the design process as a game where several players interact in order to reach a common objective. In the course entitled Introduction to Design Inquiry, given by William Porter at MIT in Fall 2002, this type of simulation was tested with the Silent Game (Figures 1 and 2). Other types of games, namely the ones suggested by John Habraken in *Concept Design Games*, explore different aspects of the design process, such as hierarchical structure, relation between forms, etc.

This research is concerned with the notion of feedback in the design process, and how it can be improved so as to contribute for an overall better end product. Due to the fact that design activity takes place making mental and physical use of one specific medium, one might argue that the use of just this one medium could be a flaw within the whole design process as it endows the designer with only one view on his ideas. In fact, having several views, i.e. multiple feedbacks, can contribute for a deeper and more informed critique upon the physical representation of those ideas.

Figure 1. Introduction to Design Inquiry, Fall 2002, *The Silent Game*: silent collaboration among players in order to reach a common objective, i.e. a final artifact.

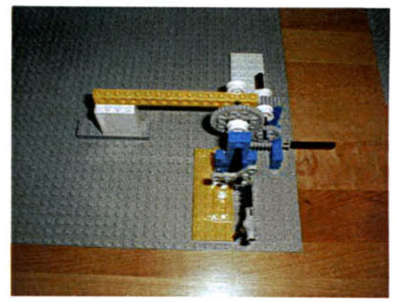

Figure 2. Introduction to Design Inquiry, Fall 2002, *The Silent Game*, final artifact.

1.2. Problem Statement

This thesis proposes the design and computer implementation of specific frameworks that simulate the design process. The idea is to represent the concept of *multiple feedbacks* through the dual presence of graphics and sound. The computer programs proposed are interfaces that allow a user to compose graphically in order to produce simultaneous audio and visual compositions. The relation between the sound and graphical outputs is defined by mapping rules that are based upon the metaphorical way in which people perceive visual data.

The frameworks proposed have a two-fold significance. Firstly, as a means to study the design process: in order to understand if multiple feedbacks actually improve the final design, test subjects will be asked to experiment the programs with and without the sound feedback. Secondly, as independent objects that either may be relevant in other fields of study or may themselves constitute new fields altogether.

1.3. Significance

Art history and art historians have always claimed that the different arts are related, to such an extent that they refer to the same styles (renaissance, baroque, neo-classical, etc), regardless of the art type (architecture, sculpture, music, etc). However, even though it is reasonable to accept that a parallel between different arts exists, namely between arts that exist upon different media, how that parallel can be accurately drawn does not seem to be so obvious. In fact, art historians generally suggest that such a relationship is very intuitive and they always refer to the overall impressions produced by the objects in question. Obviously, there are some exceptions.

In the specific case of architecture and music, the same phenomenon occurs. For example, one can find relations between Johann Sebastian Bach's compositions and Francesco Borromini's buildings in what concerns the notion of ornamentation, but no direct mapping has been suggested so far. This thesis proposes a series of mapping frameworks, implemented computationally, that establish a direct, and intended, understandable relationship between visual data and sound data through the use of specific metaphors.

Nevertheless, and especially in present times, some work regarding the mapping of data from one medium to another has been done: gestures to sound, graphics to sound, and music to color. Most frameworks relating music and visual design that have been designed so far map sound data to visual data. This thesis extends this field of study by proposing frameworks that do the same mapping but in the opposite direction, from visual to sound.

As mentioned in the previous point, the approach consists of simulating the design process by implementing a series of mapping frameworks. These mapping frameworks are actually five interactive computer programs that allow the user to design visual abstract compositions and get a sound output with musical structure. More than a means to prove a claim, these frameworks are independent objects with full significance, that is, they embody ideas and express them through (digital) representation. Obviously, these ideas are related to the overall study of the design process, but they can also be independently associated to the objects themselves. Therefore, the research carried out has led to the design and implementation of five objects that can be experienced by users outside the context defined here.

Furthermore, this investigation is on design inquiry and searches for new ways in which the design process may be improved. As such, this thesis attempts to contribute for new forms of understanding the design process, so that in the long run it can become richer and leading to a better final product.

1.4. Overview of the Thesis

The second chapter consists of background research on the relation between music and the visual arts. The first section refers to the parallel between music and architecture from an historical perspective. The following three sections are specific case studies of the twentieth century: (a) Paul Klee and the influence of music on his work, (b) Wassily Kandinsky and Arnold Schoenberg, and (c) LeCorbusier and Iannis Xenakis.

The third chapter introduces the mapping frameworks. The first section describes the basis used for their development, and the remaining sections describe each of the frameworks, namely the mapping rules and the user interfaces.

The fourth chapter describes the experiments made with different groups of people. The first section specifies how the experiments were conducted. The remaining sections describe the experiments undertaken with two different groups of test subjects; one with design background and the other with musical background. Each test subject was asked to create two compositions in each framework: one with the sound off and one with the sound on.

The fifth chapter consists of a discussion on the significance of the proposed frameworks. First, the results are compared across subject types and experimental types (with and without sound) in order to understand how relevant *multiple feedbacks* can be in the design process. Then, the frameworks are taken out of the experimental context defined in this thesis and their significance as independent objects is discussed. Lastly, a critique of the frameworks is made taking into consideration the mapping rules and the user interface.

In the sixth chapter, a general conclusion is presented and future directions are outlined.

2. Background

2.1. Music // Visual Design

Figure 3. Luis de Arevälo and F.M. Vasquez, Charterhouse, Granada, detail of sacristy.

Figure 4. Johann Sebastian Bach, Suite for Lute No. 1, BWV 996, Bourree.

Although a direct relationship between music and architecture, or rather music and visual design, is often not clear before the computer-age, parallels between the two fields can actually be found. This can be illustrated by looking at art work made during the baroque period. Regardless of the medium used, there are specific concepts that are common to baroque art in general, such as ornamentation. In Figure 3, the image of the Charterhouse's sacristy in Granada shows the simultaneous presence of structure and ornament. The austere nature of the structural elements is combined with the dynamics yielded by the ornamentation in order to contribute for an overall sober yet lively image of the whole.

In the case of Bach's Suite for Lute No.1 (Figure 4), an equivalent duality between structure and ornamentation occurs as well. Counterpoint (i.e. the contrary motion in which the pitch of treble and bass notes vary, represented in the image shown in Figure 4 by the red arrows) and polyphony (i.e. the simultaneous existence of distinct melodic lines; in this case, the treble line and the bass line represented respectively by the two sequences of red arrows) define a rigorous structure that gains dynamism through the actual intervals between successive notes, duration of notes, loudness of notes (not shown here) and subtle variations, i.e. ornamentation. In both cases, the object is composed of a clear and well-defined structure whose natural rigidity is overcome by the lightness and dynamics of the ornamentation.

An actual attempt to relate directly visual data and sound was made in the 18th century by Louis-Bertrand Castel when he

invented the ocular harpsichord (*clavecin oculaire*). The idea was to create an instrument that could simultaneously produce sound and project colors on a screen. The relation between the notes that composed the sound and the colors was based on Castel's belief that the musical scale of twelve tones had to be somehow related to the circle of twelve colors. He actually defined a mapping table of colors and musical tones (Figure 5). Based on Castel's ideas, a natural scientist named Johann Gottlob Krüger proposed an ingenious implementation of the ocular harpsichord: every time a string was plucked a diaphragm would open and, through colored lenses, would let the light of a candle be projected on a screen (Figure 6).
The ultimate objective was to have a pleasant piece played on the harpsichord be mapped to a pleasant abstract composition of colors projected on the screen.

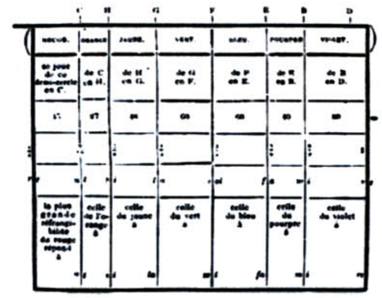

Figure 5. Table of colors and musical tones.

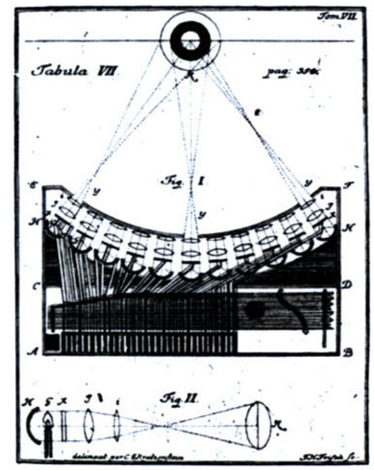

Figure 6. The ocular harpsichord implemented by Kruger.

2.2. Paul Klee

One of the characteristics of the Bauhaus was that artistic education should not focus solely on one specific art but should contemplate the potential contributions of art in general for the development of artists. And music was not an exception. The theoretical background which served as a basis for many of the classes, namely the ones lectured by Paul Klee, was partially based on the relation between music concepts and painting. This had probably to do with the fact that he was exposed thoroughly to music since a very early age. The following points describe different ways in which Paul Klee incorporated these concepts into his own work.

2.2.1. *Conductor's Gestures*

In the book that Klee wrote, *The Thinking Eye*, the elements and processes that he regards as fundamental in painting are described. Klee's theory of form starts with the study of the line as resulting from the motion of a point in space. In the physical world there are several ways in which a point describes a line; Klee is particularly interested in the lines described by the conductors' movements because they also represent rhythm (as described further, the notion of rhythm is of fundamental importance in his work). Not only was he influenced directly by the conductor's movement in a series of paintings of ships (Figures 7 and 8), he also analyzed in-depth ways of decomposing it in order to obtain visual and rhythmical significance, combining both the idea of structure (shorter lines) and melody (initial line) (Figures 9). This type of graphics can be found in several of his works namely in *Drawing with Fermata* (Figure 10). Also, Klee frequently explores the graphical potential of musical notation symbols such as the fermata by incorporating them meaningfully in his work.

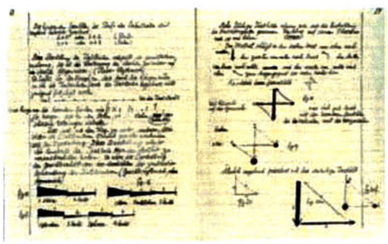

Figure 7. Paul Klee's lecture notes from pages 50 and 51.

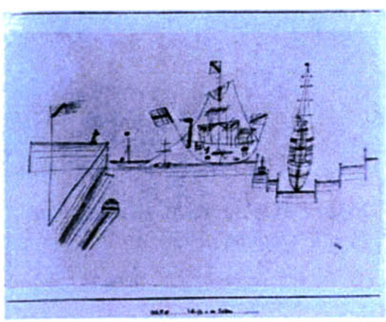

Figure 8. Paul Klee, *Departure of the Ships*, 1927.

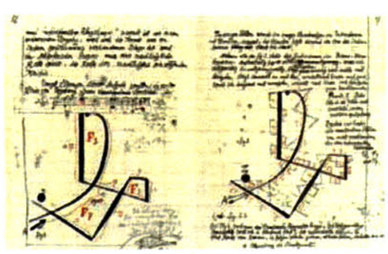

Figure 9. Paul Klee's lecture notes from pages 56 and 57.

2.2.2. *Rhythmic Divisions*

Music was of significant importance for Klee in different ways. His exposure to music and music theory provided him with particular fascination for the relation between the duration of notes and beats, i.e. rhythmic divisions. In music, the way the duration of notes is established is usually by a simple division by two or three; the following notes have equivalent duration: one whole note, two half notes, four quarter notes, eight eighth notes, 16 16th notes, 32 32nd notes, 64 64th notes, etc. Klee

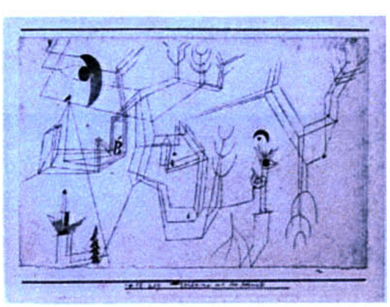

Figure 10. Paul Klee, *Drawing with Fermata*, 1918.

wanted to express this type of simplicity in his work, and he did it through the notion of Structural Rhythms.

In *Monument in Fertile Country*, the horizontally adjacent parallelograms' heights are related to each other by simple division in half. Also, the structural character of the watercolor is enhanced by the fact that the sides of the different parallelograms often match and define alignments. The musical equivalent would be to have a composition made of whole, half, quarter and eighth notes.

Figure 11. Paul Klee, *Monument in Fertile Country*, 1929.

2.2.3. *Basic Elements*

Another concept that Klee took from music into his work was the use of a limited number of basic elements in order to build complexity. In western music, the fact that there are only 12 notes in an octave does not limit a composer's creativity in any way; in fact, those 12 notes can be combined in an infinite number of ways in order to create a composition. However, they do provide a composer with an underlying structure on which musical theory is based, and, therefore, yield more control over the act of composing in general.

Figure 12. Paul Klee, *Dogmatic Composition*, 1918

In *Dogmatic Composition*, the basic elements used are rectangles, crosses, circles and semi-circles, yet the complexity of the final composition is such that it yields innumerable possibilities for interpretation. *Pastoral (Rhythms)* suggests a different approach of expressing musicality in a two-dimensional composition. The basic elements are inserted in a grid of parallel and perpendicular lines. Then, using symmetry and rotation (mirroring and inverting), the elements are rearranged in a way that is somewhat similar to what Johann Sebastian Bach did in *The Art of Fugue*.

Figure 13. Paul Klee, *Pastoral (Rhythms)*, 1927.

Figure 14. Paul Klee, *Polyphony*, 1932.

Figure 15. Francisco Tárrega, *Recuerdos de la Alhambra*, first four measures.

2.2.4. *Polyphony*

> **Polyphony**. Music that combines several distinct melodic lines simultaneously. In principle, the term is used to contrast with monophonic music, which consists of a single melodic line, and homophonic music, which consists of several lines moving at the same time in the same rhythm. [1]

Adapting the concept of polyphony to visual compositions was probably Klee's most significant contribution in what concerns the idea of painting music. He approached this concept by representing two different themes in his paintings. In terms of media, one of the themes is materialized by a composition of points and the other by a less rigid composition of colored shapes (Figure 14). Polyphony is then achieved through the overlay of both compositions.

In his compositions for the classical guitar (Figure 15), Spanish composer Francisco Tárrega clearly defined distinct melodies for the treble and bass parts, which, in a way, corresponds to what Klee did visually. Each one of the melodies can be individually perceived by a listener; simultaneously, the composition can be perceived as a whole that is more meaningful than the just the sum of the parts.

2.3. Wassily Kandinsky

2.3.1. *Visual Interpretation of Music*

A more direct relationship between the visual arts and music was proposed by Wassily Kandinsky in his book *Point and Line to Plane*. For him, points and lines are entities that can map sound to visual data in a clear way. Different types of lines (straight, curved, angular, thick, thin, etc) can represent different types of melodies; however they always represent continuity of sound, whereas points represent more syncopated notes. The relationship that he proposes is actually a more expressive form of the traditional musical scores (Figure 16), where size and width map to volume, y-position maps to pitch and x-position maps to temporal position within the overall sequence.

The type of instrument also has influence on the breadth of the line that represents it. For Kandinsky, high-pitch instruments such as the flute or the violin and low-pitch instruments such as the tuba or the double bass are naturally and respectively represented by thin and thick lines. Also, there are some instruments that predominantly suggest points, like the piano, and others lines, like the organ.

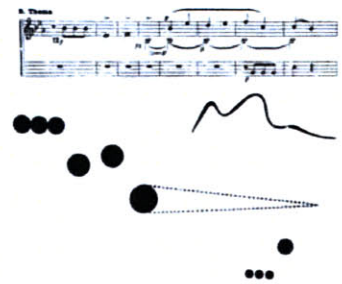

Figure 16. Wassily Kandinsky, Beethoven's Fifth Symphony translated into points and lines.

2.3.2. *The Modern Harmony in Painting and Music*

> I am certain that our modern harmony is not to be found in the 'geometric' way, but rather in the anti-geometric, antilogical way. And this way is that of 'dissonances in art['], in painting, therefore, just as much as in music. And 'today's' dissonance in painting and music is merely the consonance of tomorrow. [2]

In a more indirect way, Kandinsky and music composer Arnold Schoenberg established an almost ideological relationship between the two arts by exploring the idea of dissonance as a means to obtain harmony and significance. Schoenberg did that in music using composition in twelve tones, where the important factor was not finding consonant relationships between notes, but creating an initial sequence of twelve different tones, of the chromatic scale, and rearranging it (inverting, mirroring, overlapping, shrinking, extending, etc) so as to generate musical significance, again somewhat like Johann Sebastian Bach's *The Art of Fugue*. Thus, polyphony

Figure 17. Wassily Kandinsky, *Composition V*, 1913.

Figure 18. Wassily Kandinsky, *Composition VI*, 1913.

Figure 19. Wassily Kandinsky, *Composition VII*, 1913.

and free chromaticism were key concepts in most of Schoenberg's works.

This new revolutionary form of music composition corresponded somewhat to Kandinsky's change of posture towards painting, from figurative to abstract. In her book, *Kandinsky Compositions*, Magdalena Dabrowski refers the parallel that can be drawn between both artists' work:

> As Schoenberg had done, Kandinsky searched for a free chromatic field, probably best exemplified in his Composition VII (1913), where richly structured, polyphonic motifs create spatial and compositional ambiguities, visual beauty, emotional impact, and intellectual stimulation. The elements "constructing" Kandinsky's Compositions that are at first glance abstract, such as in the three pre-war works, Compositions V, VI, and VII, could be compared to Schoenberg's use of unresolved dissonance: one dissonance, followed by another, and then the next, without completing the expectations of the musical destination. In Kandinsky's Compositions, numerous motifs - either abstracted from natural objects as in the first six works, or more purely abstract as in Composition VII - are organized into visual structures that can be experienced simultaneously, without expecting a resolution, and that can exert emotional impact on the viewer on several physical, psychological, and emotional levels. [3]

2.4. Le Corbusier and Iannis Xenakis

2.4.1. *The Golden Number*

The Golden Number is frequently found in nature and in the arts. The notion of perfect proportions or perfect relationships of size between distinct elements is often based on this number. Mathematically, the Golden Number is defined using the Fibonacci sequence.

The Fibonacci sequence's definition consists of:

(a) Fib is a discrete function;

(b) the first two elements are 0 and 1: **Fib(0) = 0, Fib(1) = 1**;

(c) each element is equal to the sum of the previous two elements:

Fib(n) = Fib(n-1) + Fib(n-2), where n is an integer;

The first elements are thus: 0 1 1 2 3 5 8 13 21 34 55…

The Golden Number is defined as:

$$G = \lim_{n \to \infty} \frac{Fib(n)}{Fib(n-1)} \quad \leftrightarrow \quad G = 1.618\ldots$$

2.4.2. *Design and Musical Applications*

Innumerable conscious applications of the Golden Number have been made in varied fields of study. In architecture, it has been thoroughly explored by Le Corbusier as means to create meaningful relationships between body and building. As he has demonstrated in *Le Modulor*, the dimensions of the human body are based upon this magic number (Figure 20). The buildings designed by him are examples of concrete applications of the Golden Number not only in terms of the dimensional relationship between the space and the user of the space but also in terms of the proportion of the very architectural elements.

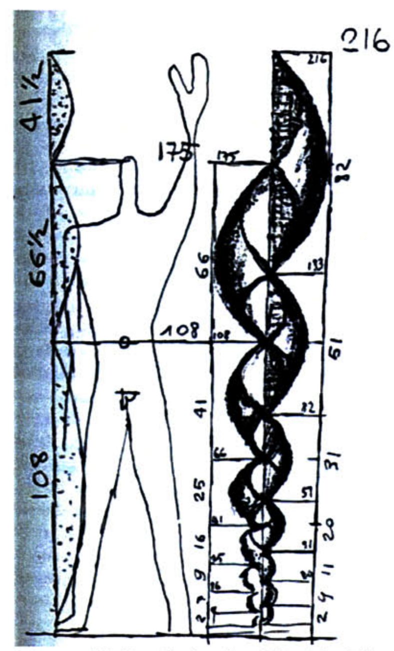

Figure 20. Le Corbusier, The Modulor.

Although not having deep knowledge of mathematics, Le Corbusier worshiped it because mankind's understanding of the world is based upon it:

> Mathematics is the majestic structure conceived by man to grant him comprehension of the universe. It holds both the absolute and the infinite, the understandable and the forever elusive. It has walls before which one may pace up and down without result; sometimes there is a door: one opens it – enters – one is in another realm, the realm of the gods, the room that holds the key to the great systems. These are the doors of miracles. [4]

Thus, in numerous designs of his, mathematics played a fundamental role, not just by using the Modulor as a tool for architectural design, but also by exploring geometry in innovative ways, which was why Iannis Xenakis, an engineer who had deep knowledge of mathematics, was recruited to his office.

Xenakis was impressed with the proportions of the Modulor, and immediately foresaw potential applications of it outside the field of architecture, namely in music. *Metastasis* was composed by him in 1954 and consisted of the application of geometrical progressions, in particular the Golden Section (mentioned in the Modulor), in the intervals and durations of notes in the composition.

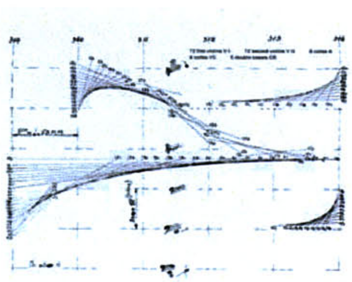

Figure 21. Iannis Xenakis, Diagram of glissandi from Metastasis, 1954.

Xenakis's producer described *Metastasis* as follows: "Systematic employment of individual *glissandi* [sliding sound] by the entire mass of strings of an orchestra; the slopes of these *glissandi* are calculated individually. These *glissandi* create sound spaces of continuous evolution, comparable to ruled surfaces and volumes. It is these *glissandi* precisely that led the author some years later to the conception of the Philips Pavilion at the Brussels Exposition of 1958, for Le Corbusier..." [5] In fact, observing an image of the Philips Pavilion (Figure 22), the resemblance between the diagram of the glissandi and the actual pavilion becomes clear.

Figure 22. Le Corbusier, Philips Pavilion, Brussels, 1958.

The relationship between music and architecture established by the work of Le Corbusier and Xenakis is of a different nature than in the previous examples, where the relationship was based on the concept of mapping. In this case, music and architecture are related by a common generator of artistic substance: Mathematics. This link between the two fields had already been explored in past times, namely during Greek

Antiquity and the Renaissance, when both music and architecture were deeply based on the use of mathematics as a means to reach perfection.

3. Description of the Mapping Frameworks

3.1. Metaphorical Interpretation

Metaphorical thinking is one of the foundations of human communication. Although we frequently disregard it, most of the abstract concepts that we as humans express are in fact based upon the use of metaphors. For example, the literal interpretations of the following expressions, suggested by George Lakoff, are meaningless within the context of psychological difficulty: "He's trying to get around the regulations."[6] "We ran into a brick wall."[7] "Get off my back."[8] "I'm out of gas."[9]

The very nature of abstract concepts makes them (almost) impossible to be expressed literally. Therefore, languages, and in particular the English language, make use of comparisons to literal physical situations in order to convey the meaning of those concepts.

In *The Contemporary Theory of Metaphor*, George Lakoff, referring to the nature of metaphor, claims that "metaphor is the main mechanism through which we comprehend abstract concepts and perform abstract reasoning"[10] and, referring to the structure of metaphor, claims that "metaphors are mappings across conceptual domains"[11].

Being the visual language in fact a language, Lakoff's ideas also apply to it. A viewer's interpretation of an abstract painting often refers to exterior concepts that are more familiar to him. As such, it is not unusual for someone to use the concept of gesture in their appreciation of a work of sculpture, or concepts taken from music in order to describe a visual composition.

This theoretical background served as a basis for the design and development of the frameworks proposed in this thesis. In order to obtain an audio-visual feedback from a composition that was generated by the direct manipulation of graphical variables, a mapping from graphics to sound has to be defined. Therefore, in each of the frameworks, a series of mapping rules was designed in order to support a specific idea of metaphorical interpretation of visual data. Different types of visual compositions yield different readings altogether. The sound outputs generated by each of the proposed frameworks are concrete representations of possible musical interpretations of visual data. The idea is to aim at universal and naturally accepted mapping rules for each type of visual composition.

The following sections of this chapter describe the characteristics of each of the five mapping frameworks.

3.2. *VisualScores*

Figure 23. Example of a composition in *VisualScores.*

Contrast between foreground color and background color	→ Duration of note
Size / area	→ Volume of note
Y-Position	→ Pitch of note
X-Position	→ Position of note in the melody
Shape	→ Instrument
Sound Feedback:	Music is played after the composition is defined
Reading:	From left to right
Metaphor:	Musical Scores – Cultural convention

Table 1. Mapping rules for each object in the framework, and characteristics.

The idea behind *VisualScores* is to create abstract compositions in the same way that composers write musical scores; this means that information is encoded in the graphical data and that specific syntax and semantics exist in order to extract that information, much like writing; in this case, that's what the computational mapping framework will do. This framework's mapping rules are based on the algorithm that relates graphics and music within the context of vertical balance proposed by José Pinto Duarte in his Master's thesis[12].

In *VisualScores*, a user creates a composition by drawing geometric objects against a background. These objects can be of several sizes and proportions, but are always rectangles, ovals, or triangles. Both the background color and the objects color can be defined by the user. Each one of the objects maps to a specific sound (pitch, volume, time, etc) according to its characteristics (size, color, shape). The mapping rules consist of: size maps to volume, contrast of color between object and background maps to length of note and shape maps to instrument (ovals map to percussion, rectangles map to piano, and triangles map to flute). In this framework, as eventually could be expected, color does not influence the pitch of the note whatsoever. Color is important in the sense that if foreground color and background color contrast much, then the perceptual impact of that specific object will be of greater importance and, as such, that will be mapped to the sound output by making the respective note last longer.

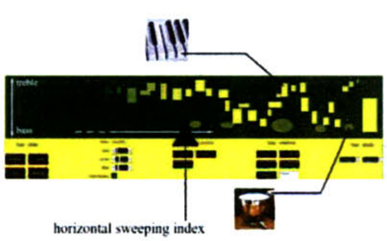

Figure 24. *VisualScores* – concept.

There are two main factors that make this framework metaphorically equivalent to musical scores: the pitch of the note is defined by the y-position of the object and the place of the note within the melody, that is, the time at which it is played is defined by the x-position of the object.

3.3. *KandinskyLines*

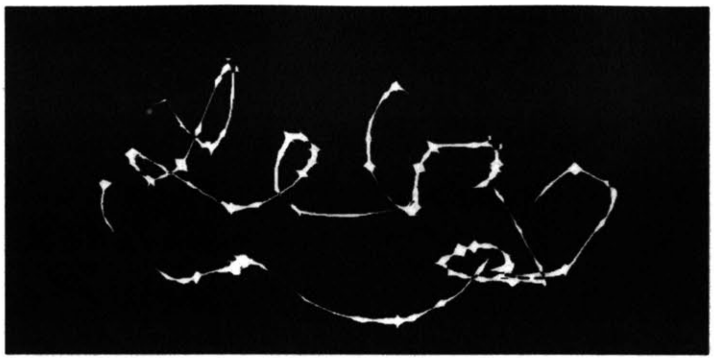

Figure 25. Example of a composition in *KandinskyLines.*

Y-Position	→ Pitch of note
Width of the line, at a specific point	→ Duration of note
Angle to the horizontal, at a specific point	→ Duration of note
Sound Feedback:	Music is played after the composition is defined
Reading:	Along the line
Metaphor:	Gravity – Physical

Table 2. Mapping rules and characteristics of the framework.

The goal of *KandinskyLines* is to simply translate one line into a melody. Unlike *VisualScores*, the main idea is to produce sound as the line is read from beginning to end, and not from left to right. The line is defined by the user as he scribbles on the display of the interface, therefore the line can be straight, curvy, edgy, etc. Moreover, the thickness of the line is defined by the speed at which the scribble is made: the slower the stroke, the thicker the line (Figure 25).

As mentioned above the line is read from beginning to end, and the point at which, at a specific time, it is read is marked by a gray dot. The y-position of this dot determines the pitch of the note that is produced at that moment: the higher the dot is, the higher the pitch (Figures 26 and 27). The x-position of the dot has actually no impact on the sound output. As such, when the animation is played, the dot moves along the line, somewhat like a roller-coaster, and it is accompanied by the respective melody. Another important factor that enhances the roller-coaster and gravity effect is the fact that dot's speed decreases when the line is tilted upward and increases when it's tilted downward. The speed also depends on the thickness of the line (which had to do with the speed of the stroke in the first place): the thicker the slower.

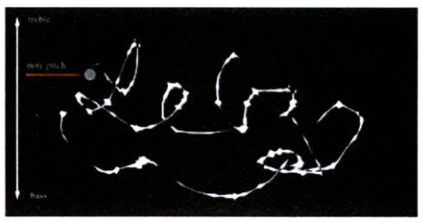

Figure 26. Starting point.

Figure 27. Intermediate point.

3.4. ***RecursiveRhythm***

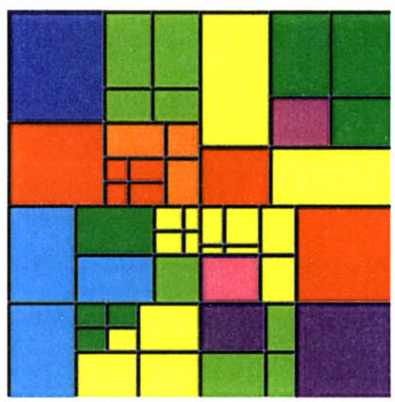

Figure 28. Example a composition in *RecursiveRhythm.*

Color	→ Pitch of note
Width	→ Duration of note
Height	→ Volume
Sound Feedback:	Real-time as user composes
Reading:	In-depth clockwise
Metaphor:	Circular - Geometrical

Table 3. Mapping rules for each rectangle in the framework, and characteristics.

RecursiveRhythm is a framework for creating visual compositions whose reading, like the previous ones, is based on a metaphor that relates visual data and sound data. However, in this case, instead of using a metaphor of cultural nature based on the concept of musical scores (reading from left to right), the metaphor is based on geometry. In fact, not all compositions are predominantly horizontal, like the one shown in the *VisualScores*; whenever the circumscribing frame does not privilege any direction (i.e. if it's square, circular, etc), the reading of the composition is not likely to be comparable to that of a musical score. *RecursiveRhythm* suggests a different way to interpret visual data.

Figure 29. Basic rule.

- Visual Composition

A session with *RecursiveRhythm* begins with the creation of a visual composition. As the name suggests, the idea is to divide the main frame (largest square) sequentially and recursively into smaller squares. The division rule is based on the simple shape grammar rule[13] shown in Figure 29.

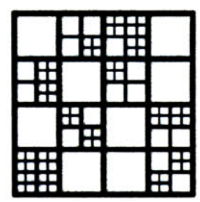

Figure 30. Composition, example.

If the rule is applied over and over to the smaller squares, the final result may look something like the design on Figure 30.

The rule is applied to a particular square whenever the user left-clicks on that square. Moreover, at any point of the process the user may change parametrically the proportions of the squares turning them into rectangles, by clicking on the lines and dragging them (Figure 31).

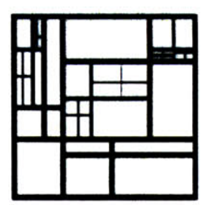

Figure 31. Composition with parametric variations, example.

Composing with *RecursiveRhythm* also implies the use of colors. Each one of the rectangles in the composition has a specific color belonging to the circle of colors (12 colors – primary colors: yellow, red and blue; secondary colors: green, orange and violet; and tertiary colors: yellow-orange, red-

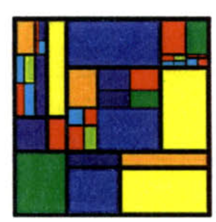

Figure 32. Composition with colors, example.

orange, red-violet, blue-violet, blue-green and yellow-green). The user may change the color of a specific square just by right-clicking on it (Figure 32).

- Sound Composition

The visual compositions created produce a sound output according to specific mapping rules. In this case, for each of the rectangles, they consist of:

(a) color → pitch/note
(b) width → duration of note
(c) height → volume
(d) reading → depth-first, clockwise

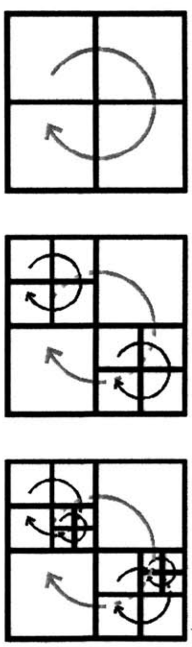

Figure 33. Depth-first clockwise reading.

The musical sequence is built by reading the composition rectangle by rectangle in a clockwise and depth-first manner, starting with upper-left rectangle (Figure 33).

Therefore, as the user builds a composition, there will be real-time sound feedback. In terms of rhythm, as the composition begins to take shape, so does the structure of the musical sequence. In the example that follows, each measure corresponds to one loop:

Figure 34. Initial rhythm of the musical sequence.

Figure 35. Division of the initial rhythm.

Figure 36. Further division of the rhythm.

Figure 37. Variation of note duration by means of parameter change.

As mentioned previously, the color of the rectangles maps to pitch. The twelve colors of the circle of colors respectively produce the sound of the twelve tones in the chromatic scale. As such, the color yellow is arbitrarily associated with the note C, and from there, each color on the circle of colors is associated to a note on the chromatic scale:

Yellow	→	C
Yellow-Orange	→	C#
Orange	→	D
Red-Orange	→	D#
Red	→	E
Red-Violet	→	F
Violet	→	F#
Blue-Violet	→	G
Blue	→	G#
Blue-Green	→	A
Green	→	A#
Yellow-Green	→	B

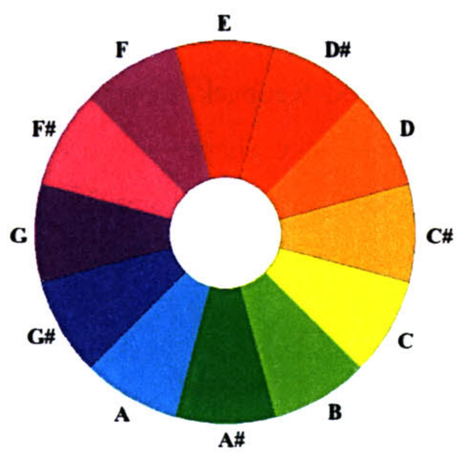

Figure 38. Mapping of the color wheel to the chromatic scale.

In *RecursiveRhythm*, closeness of colors maps to closeness of note frequency, therefore, visual dissonance and consonance are not mapped to the sound output.

The following example shows both the color and the geometrical aspects of the visual composition translated into a musical sequence:

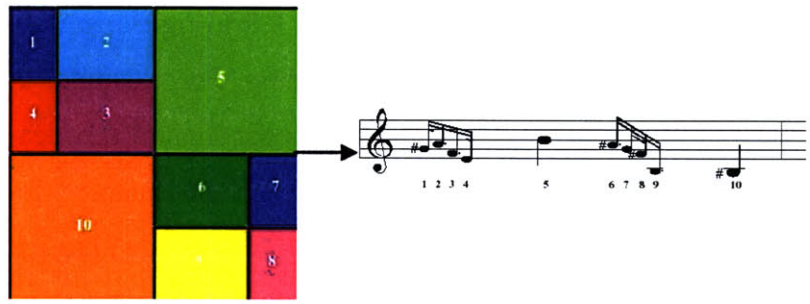

Figure 39. Translation of visual data into a musical sequence.

3.5. *SchoenbergScribbler*

Figure 40. Example of a composition in *SchoenbergScribbler*.

Length	⟶ Duration of note
Color	⟶ Pitch of note within an octave
Y-Position	⟶ Octave
Sound Feedback:	Music is played after the composition is defined
Reading:	Along each stroke; each one has its own vibration
Metaphor:	Organism – Biological

Table 4. Mapping rules for each object in the framework, and characteristics.

The design of *SchoenbergScribbler* is based on Schoenberg's *Twelve Tone Composition*. However, composing with twelve tones in Schoenberg's way is extremely complex, so for this framework, only a few concepts of his theory are taken into consideration.

The reading of a visual composition, as mentioned previously, depends on how the composition is structured in the first place. Therefore, if some compositions yield a left-to-right reading, others yield non-orthodox forms of reading. For example, a Jackson Pollock painting (Figure 41) does not support the idea of sequential elements in time and space; on the contrary, in that particular case, each of the elements (paint strokes) has its own vibration, and the sum of all the vibrations contribute for the viewer's interpretation of it.

Figure 41. Jackson Pollock, *Autumn Rhythm*, 1950.

In *SchoenbergScribbler*, the user produces four paint strokes that map individually and simultaneously to specific sound sequences. The idea is that each one of the paint strokes maps to a sequence of the twelve tones in the chromatic scale from lower to higher increasing at each step by half-tone. The octave which the sequence belongs to is defined by the y-position of the stroke start point, such that the higher it is, the higher the pitch. Furthermore, the speed at which the notes in the sequence are played depends on the size of the stroke, so, as a consequence, if the four strokes have different lengths, they produce similar sequences of notes, but because the speed at which they are played is different, there is a sense of constant change in the sound output without repetition whatsoever (Figure 43).

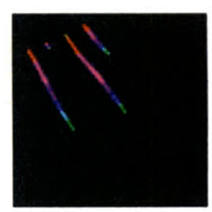

Figure 42. Example of a design using *SchoenbergScribbler*.

The color used in this framework is merely symbolic as each one of the twelve tones is represented by one of the twelve colors of the color wheel.

Figure 43. Sound output relative of the design shown in Figure 42.

Figures 42 and 43 show that it is in fact difficult to obtain a repetitive pattern when all four melody lines are considered. Figure 43 is not quite accurate because the notes of each line might actually belong to a different octave, but it illustrates the idea mentioned above.

3.6. *Albers'sDissonances*

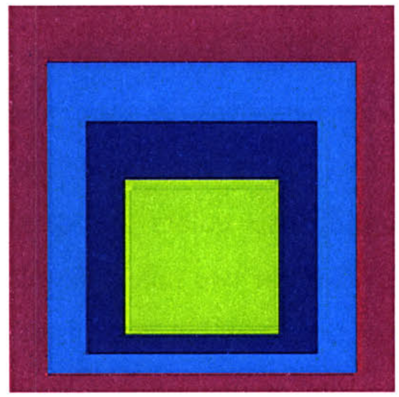

Figure 44. Example of a composition in *SchoenbergScribbler*

Relation between adjacent colors	→ Relation between notes (interval), first note arbitrarily chosen, pitch gets higher
Sound Feedback:	Music is played after the composition is defined
Reading:	Inside out
Metaphor:	Perspective – Perceptual

Table 5. Mapping rules for each object in the framework, and characteristics.

Albers'sDissonances is a framework that maps visual compositions based on Josef Albers's paintings to a sequence of notes. The series of paintings that Albers worked on, *Study for Homage to the Square*, is unique in the sense that it tries to explore the individuality of each shape by means of dissonance of colors. No one shape is seen as an extension of another one, but always as an independent entity that has its own voice in the overall context defined by all shapes. The important parameters in these studies are not the shapes or even the colors of the shapes, but the relation between the colors of "sequential" elements.

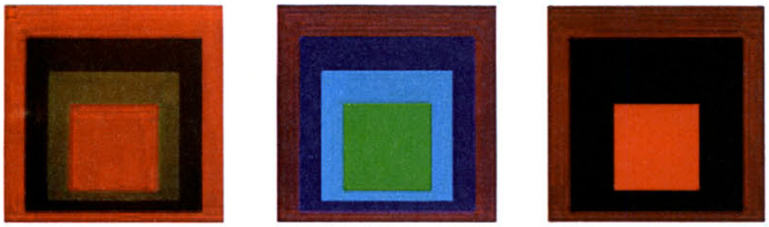

Figure 45. *Study for Homage to the Square 1973, 1960, 1954*, Josef Albers.

The main idea of the design of the framework is to map the relation between two colors to the relation between notes (interval): therefore if two colors are close (for example, yellow and orange) then the two notes played will be close as well, not in terms of frequency but in terms of consonance (for example, C and G, that is one fifth). Closeness in terms of consonance is defined as follows:

interval	Oct	5th	4th	M6	M3	m3	m6	m7	M2	M7	m2	Tri
½ tones	12	7	5	9	4	3	8	10	2	11	1	6
ex.	C	G	F	A	E	D#	G#	A#	D	B	C#	F#
diss.	→ + dissonant											
cons.	← + consonant											

Table 6. Intervals.

Four notes are played sequentially with a partial overlap, as shown in Figures 46 and 47.

The first note played is always arbitrarily C and corresponds to the inner most square, and from there the second note is defined by closeness of colors between that square and the second inner most square: if the first color and the second color are adjacent in the color wheel then the second note will be

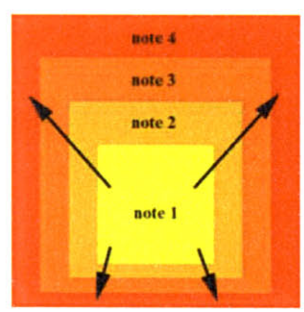

Figure 46. Reading sequence

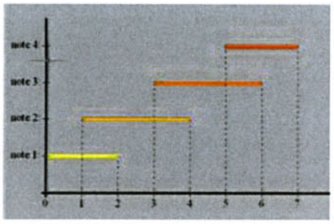

Figure 47. Partial overlap of sequential notes

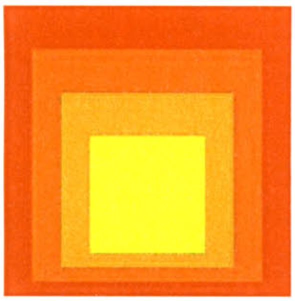

Figure 48. Example 1.

either the fifth or the fourth (G or F) according to whether it is adjacent clockwise or counter clockwise.

Once the second note is played, its relation to the upcoming third note is defined by rearranging the set of ordered consonances having either G or F as the main note (octave). The following tables and diagrams illustrate more clearly, in two specific examples, the algorithm that maps relation of colors to note intervals.

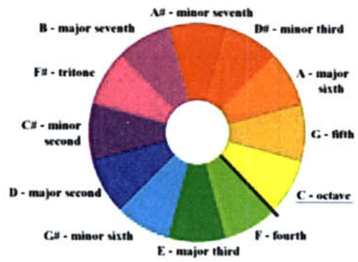

Figure 49. 1st note played: C; relation between colors and notes.

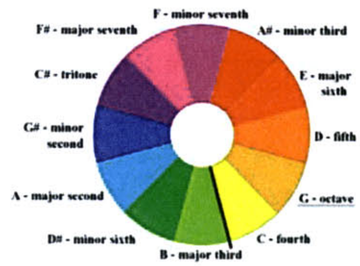

Figure 50. 2nd note played: G; updated relation between colors and notes.

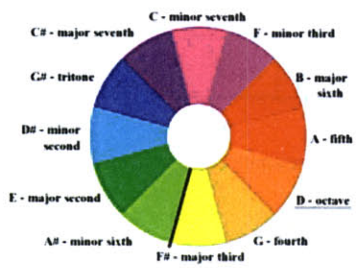

Figure 51. 3rd note played: D; updated relation between colors and notes

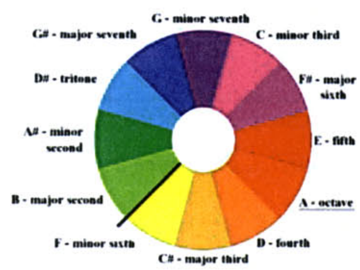

Figure 52. 4th note played: A; updated relation between colors and notes

Interval	Number of c. or cc. steps along the circle *	n. ½ tones	Intervals in relation to C	Intervals in relation to G	Intervals in relation to D	Intervals in relation to A
octave	0	12	C(1ST)	G(2ND)	D(3RD)	A(4TH)
fifth	1cc	7	G(2ND)	D(3RD)	A(4TH)	E
fourth	1c	5	F	C	G	D
M6	2cc	9	A	E	B	F#
M3	2c	4	E	B	F#	C#
m3	3cc	3	D#	A#	F	C
m6	3c	8	G#	D#	A#	F
m7	4cc	10	A#	F	C	G
M2	4c	2	D	A	E	B
M7	5cc	11	B	F#	C#	G#
m2	5c	1	C#	G#	D#	A#
tritone	6	6	F#	C#	G#	D#

* c.: clockwise; cc.: counter-clockwise

Table 7. Updating the intervals in terms of consonance/dissonance

Whenever a note relative to a specific color is played, the program generates a custom color-note wheel that determines how the following note to be played will be selected. As can be observed on Figures 49 and 50, the note being played is the underlined one, and as one gets further away from that color clockwise or counter-clockwise along the wheel, the interval that determines the following note becomes gradually more dissonant. Ultimately, the exact opposite side of the wheel is reached, which corresponds to the tritone, the most dissonant of all intervals. It's important to notice that the intervals become gradually more dissonant in both the clockwise and counter-clockwise direction; this is done by assigning to each step along the circle every other interval in the sequence of consonant/dissonant intervals described above. As such in the clockwise direction, the intervals along the circle are: octave, fourth, major third, minor sixth, major second, minor second and tritone; and in the counter-clockwise direction: fifth, major sixth, minor third, minor seventh, major seventh, and closing again with tritone (Table 7).

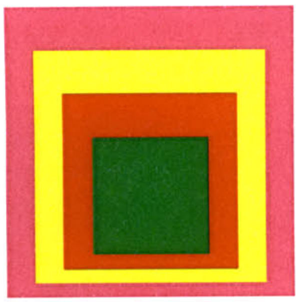

Figure 53. Example 2.

In the second example, the composition is not based on adjacent color-wheel colors like the previous one, but on contrasting and opposite colors, in the spirit of Albers's *Study for Homage to the Square*. As may be observed on Figure 54 through Figure 57, both the colors and the notes stand apart from each other. In this case, sound output will be based on a sequence of notes that define highly dissonant intervals, to be in accordance with the dissonance suggested by the visual composition.

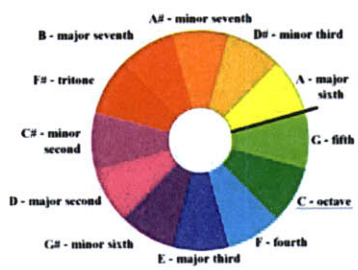

Figure 54. 1st note played: C; relation between colors and notes

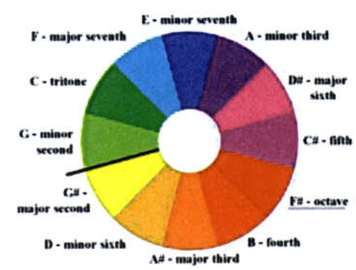

Figure 55. 2nd note played: F#; updated relation between colors and notes

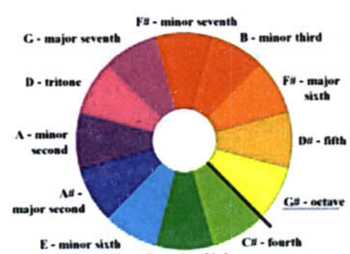

Figure 56. 3rd note played: G#; updated relation between colors and notes

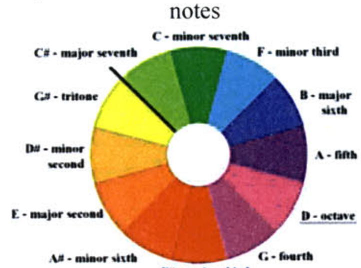

Figure 57. 4th note played: D; updated relation between colors and notes

Interval	Number of c. or cc. steps along the circle *	n. ½ tones	Intervals in relation to C	Intervals in relation to F#	Intervals in relation to G#	Intervals in relation to D
octave	0	12	C(1ST)	F#(2ND)	G#(3RD)	D(4TH)
fifth	1cc	7	G	C#	D#	A
fourth	1c	5	F	B	C#	G
M6	2cc	9	A	D#	F	B
M3	2c	4	E	A#	C	F#
m3	3cc	3	D#	A	B	F
m6	3c	8	G#	D	E	A#
m7	4cc	10	A#	E	F#	C
M2	4c	2	D	G#(3RD)	A#	E
M7	5cc	11	B	F	G	C#
m2	5c	1	C#	G	A	D#
tritone	6	6	F#(2ND)	C	D(4TH)	G#

* c.: clockwise; cc.: counter-clockwise

Table 8. Updating the intervals in terms of consonance/dissonance

4. Experimentation

4.1. Description of the Experiments

In order to understand the influence on design of multiple feedbacks compared to that of a single feedback a series of experiments with test subjects was undertaken. The idea was to have them test the proposed frameworks, initially without sound and then with the sound output on.

First, they were asked to use the frameworks in order to build a composition and briefly explain what the main ideas were. After that, the subjects heard what their compositions sounded like.

Then, having been told what the mapping rules of each framework were, they were asked to compose something, but now taking into consideration the sound output. The idea was to create something that made sense from the visual perspective, from the sound perspective and from both put together; so, in this case, they also had to explain the rationale behind the final composition. They were free to try as many times as needed in order to feel comfortable with the composing constraints and until they were satisfied with the final result.

After all the frameworks were tested, the test subjects were asked which one they preferred and why.

Two groups composed of two test subjects each were considered. Subjects belonging to the first group had a design background and subjects belonging to the second had musical background. By analyzing the differences between the data (actual compositions and observations) provided by the two groups, the idea is to understand how relevant the audio part of designing with multiple feedbacks may be for designers.

The test subjects were:

(a) Rita Saad – SMArchS II; design background.

(b) Panagiotis Chatzitsakyris (Panos) – SMArchS I; design background.

(c) John Alex – PhD in Design and Computation; musical background.

(d) Jose Dominguez-Caballero (Pepe) – PhD in Mech. Engineering; musical background

For better understanding, whenever *first experiment* and *second experiment* are mentioned, they are respectively relative to the experiment without sound and the experiment with sound.

4.2 First Test Subject with Design Background

4.2.1. *VisualScores*

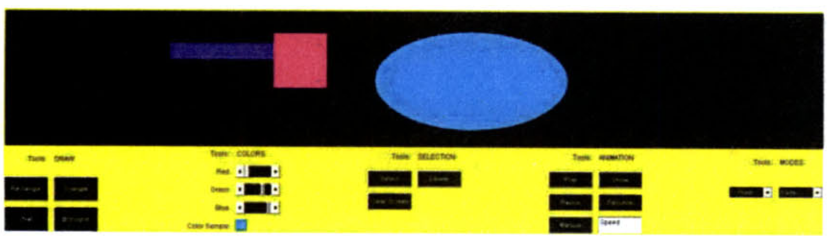

Figure 58. Rita's composition in *VisualScores* with sound off

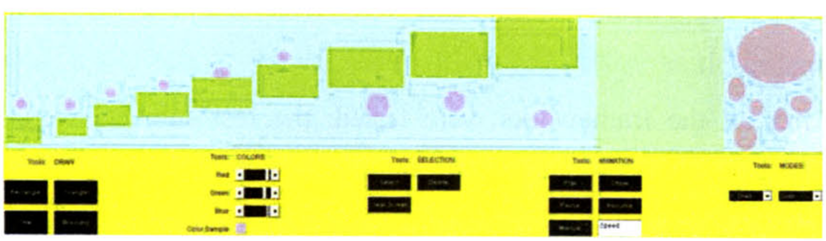

Figure 59. Rita's composition in *VisualScores* with sound on

The first experiment was meant to be strictly visual; however, and although she did not have previous knowledge of the framework's design, Rita was naturally inclined to associate the composition of shapes to a musical score. The idea consists of one first element (the stretched blue rectangle on the left) that represents a lasting and continuous sound; this continuity is broken by the insertion of a second element of concentric nature (the pink square) that represents a punctual note followed by a pause (the gap between the square and the following element). The last element, the blue oval, because its geometry is not as rigid as the rectangle's, is supposed to represent a smooth echoing fade out.

The second composition was both visual and audible, and in Rita's case the influence of musical structure in the design was clear. The idea was to have a crescendo accompanied by a subtle percussion and followed by a different type of sound that would end the composition (the pink ovals on the left).

4.4.2. *KandinskyLines*

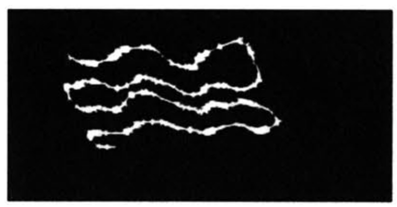

Figure 60. Rita's composition in *KandinskyLines* with sound off.

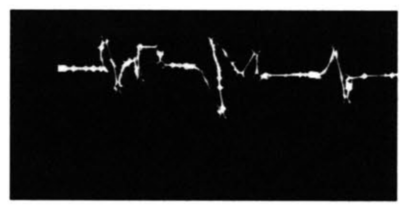

Figure 61. Rita's Composition in *KandinkyLines* with sound on.

Rita's composition for the first experiment consisted of a line that was appealing to her in some way. That consisted on having a wavy line with no intersections and that suggested constant fluctuation. Additionally, to keep the idea of smoothness, the variation of thickness within the line is minimal.

In the second experiment, the idea was to combine structure and variation, so that diverse stability could be achieved. As such, a horizontal line with punctual variations was drawn; this corresponds to having one main note throughout the whole composition that stands out from all others. Basically, it is a kind of stable equilibrium where the note produced in time may vary but tends to come back to that main one.

4.2.3. *RecursiveRhythm*

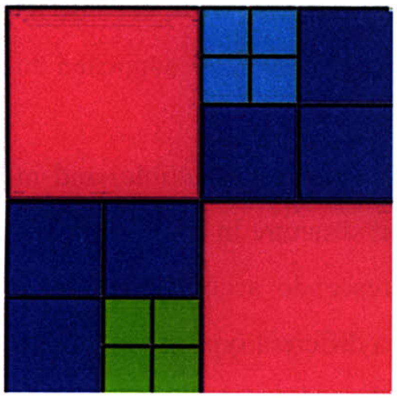

Figure 62. Rita's composition in *RecursiveRhythm* with sound off.

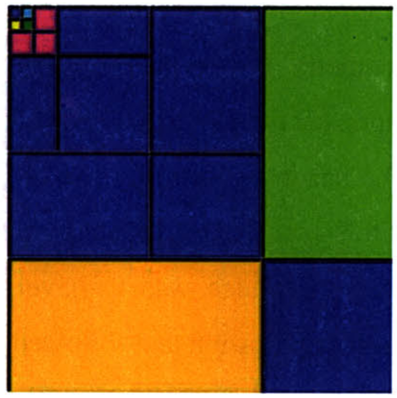

Figure 63. Rita's composition in *RecursiveRhythm* with sound on.

In the first experiment, the idea was simply to build an abstract composition whose geometry and colors was centrally symmetric.

In the second experiment, Rita worried specially about creating something that made sense both from a graphical and sound point of view. She kept the notion of symmetry, only not about a central point but about an axis – the descending diagonal. In terms of sound, she wanted to contrast a fast rhythm (smaller rectangles) with gradually slower ones (larger rectangles). As far as the colors are concerned, she felt that she did not really have much control over the way they sounded, and their mapping to specific notes was somewhat arbitrary and, consequently, irrelevant.

4.2.4. *SchoenbergScribbler*

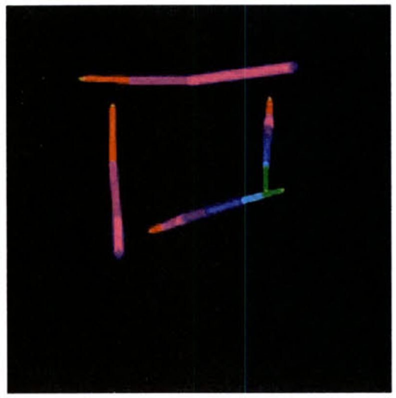

Figure 64. Rita's composition in *SchoenbergScribbler* with sound off.

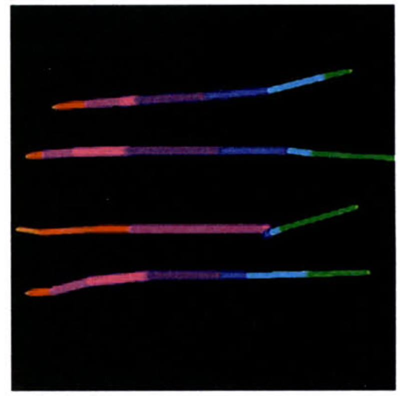

Figure 65. Rita's composition in *SchoenbergScribbler* with sound on.

Figure 64 shows Rita's first experiment with *SchoenbergScribbler*; she simply meant to use the four lines to draw a square. The idea was to have a foreground square in a square background.

As in the second experiment with *RecursiveRhythm*, the composition in Figure 65 was created paying careful attention to both the visual and audio aspects. As Figure 65 clearly shows, the idea was just to have four "identical" horizontal lines at different heights but separated by equal spacing. In terms of sound output, Rita attempted to have all twelve notes of the chromatic scale played simultaneously in four different octaves. However, both the implementation of the framework and the user interface did not allow for much control over the length and the curvatures of the strokes, and the length of each part within a stroke. Therefore, the final result was not exactly what she was hoping for.

4.2.5. *Albers'sDissonances*

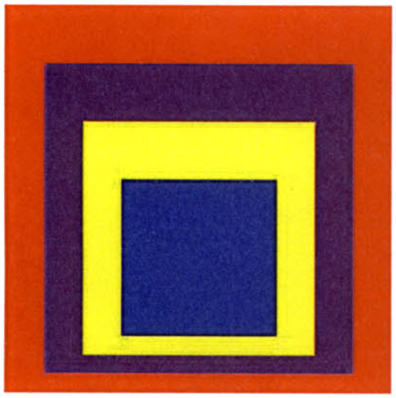

Figure 66. Rita's composition in *Albers's Dissonances* with sound off.

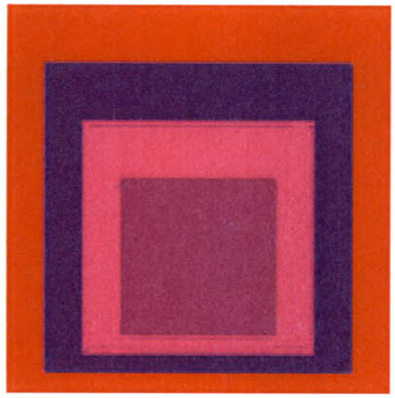

Figure 67. Rita's composition in *Albers's Dissonances* with sound on.

In the experiment relative to Figure 66, Rita's composition attempted to contradict the idea of the tunnel perspective suggested by the four squares, and she did that by means of contrasting colors. In terms of sound, it produced a sequence of dissonances that she felt was too aggressive. Consequently, when she composed with sound (Figure 67), she opted to have the squares colored just in slightly different colors yielding the perception of the tunnel, so that they would map to a sequence of relatively consonant intervals.

4.2.6. *Final Comments*

After trying out all the frameworks, Rita picked *VisualScores* as the more meaningful within this thesis's context for two reasons. First, it yields more control over both the musical and graphical composition. Second, the mapping rules seem more natural to the user than the mapping rules of the other frameworks, and as such tend to be more universal: the perception that a viewer has of the visual composition seems naturally related to the proposed sound output.

However, as far as colors are concerned, the mapping rules in *VisualScores* were not as obvious to Rita. She felt that the only framework that dealt well with the relation between colors and notes was *Albers'sDissonances*, precisely because it did not map arbitrarily colors to notes, but closeness of colors to consonance of intervals.

4.3 Second Test Subject with Design Background

4.3.1. *VisualScores*

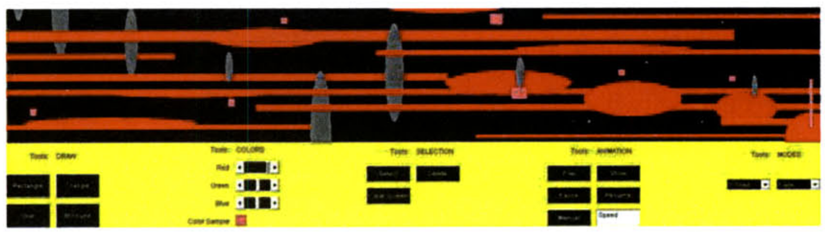

Figure 68. Panos's Composition in *VisualScores* with sound off.

Figure 69. Panos's Composition in *VisualScores* with sound on.

Panos has a design background, but he extends it with an active interest in film-making. So, for this first experiment, he intended to create a visual narrative. Once again, although he did not exactly associate this framework to the musical score metaphor from the start, he knew that his composition was to be built and read from left to right, just like a time-line on a movie editing program. The first thing he did was to set up a context, represented by the stretched rectangles (just like Rita, he figured that these would eventually map to continuous sound and contribute for a "background music"); the idea was that the action would take place in this context. After that he started populating the newly created space with characters so that a story is displayed on the screen. That story was actually very simple and basically consists of a "cliché": there is a "good guy", a "bad guy" and a girl. At some point, they meet and get into a "fight" in which the "good guy" is helped by the girl and wins. In the end, they both live happily ever after. In the composition, the "good guy", the "bad guy" and the girl are respectively represented by the red oval, the gray oval and the pink square/rectangle. As mentioned previously, the action takes place from left to right.

After hearing what the first composition sounded like, Panos understood that, for the story to make sense from an audio point of view, some changes had to be made namely in what concerned how the context was designed. In the second composition, he wanted to keep the same story. So, for setting up the context, instead of having long horizontal strips, he opted for a structured repetition of white vertical rectangles. The action and the characters' roles worked much in the same way as before: the "good guy" is the dark gray oval; the "bad guy" is the light gray one; and the girl is the dark rectangle. One curious aspect about this last composition is the fact that Panos paid particular attention to the ending. He subtly placed three diminishing rectangles on the upper right corner of the display, and, by doing so he made it clear that the ending was meant to be perceived differently than the rest of the narrative.

4.3.2. *KandinskyLines*

Figure 70. Panos's composition in *KandinskyLines* with sound off.

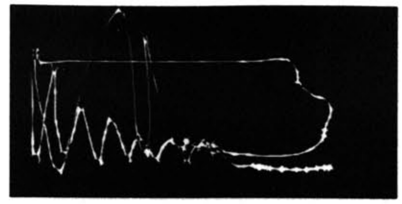

Figure 71. Panos's composition in *KandinskyLines* with sound on.

In this first experiment, Panos tried to explore the potential of the framework as a tool that can generate plasticity and expressive compositions. For that, he attempted to draw a line that resembled somewhat his own signature. However expressive the form he created might be, the relative sound output is not representative of the order perceived visually as it consists of almost random variations of notes.

In the second experiment, he tried to combine both visual expressivity and musical significance. Consequently, the line that he drew explored stability (horizontal line in the upper part of the display) and variation at first; then it engaged into a fading pattern (Figure 71) structured rhythmically like a sine wave in order to represent the closing section of the melody/composition.

4.3.3. *RecursiveRhythm*

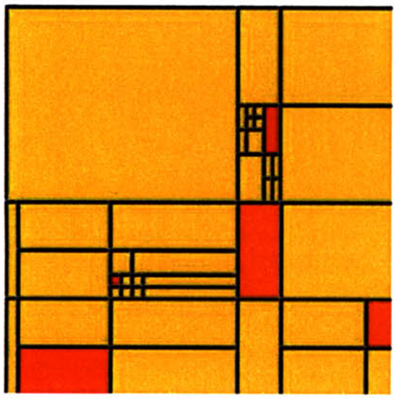

Figure 72. Panos's composition in *RecursiveRhythm* with sound off.

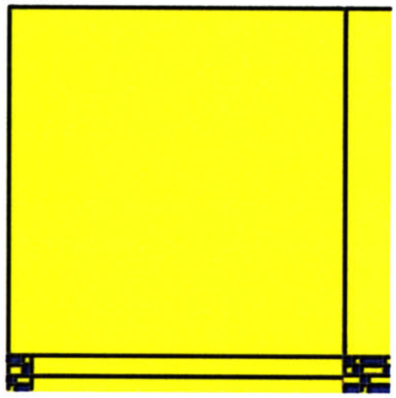

Figure 73. Panos's composition in *RecursiveRhythm* with sound on.

The composition on the left was built trying to escape symmetry but still keeping the notion of order and balance. The idea was to use the Golden Section and the 3:2 ratio to set the proportion of the rectangles. The foreground color (red) was meant to be used punctually in strategic places to support just slight variation in the composition so that the overall impression was clear and sober. However, that impression was not mapped at all to the sound output; in fact, it was quite chaotic.

For the composition on the right, keeping the same will to escape symmetry, Panos tried to create a visual contrast that could actually be heard as well. So the contrast in the graphical composition consisted of contrast of sizes and of colors, which mapped to the contrast in the audio composition, of duration of notes and of intervals.

4.3.4. *SchoenbergScribbler*

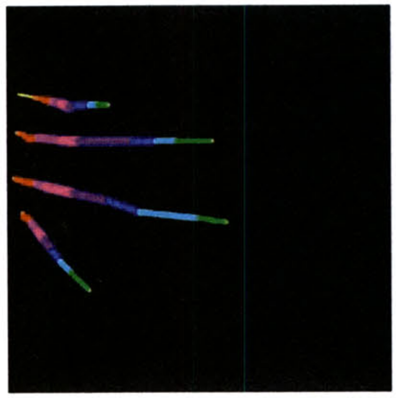

Figure 74. Panos's composition in *SchoenbergScribbler* with sound off.

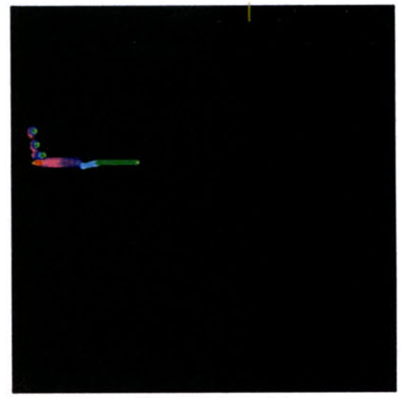

Figure 75. Panos's composition in *SchoenbergScribbler* with sound on.

In the case of *SchoenbergScribbler*, the first experiment consisted of a very simple composition where different sized strokes suggest a downward movement. It can also be regarded as a clear representation of a hand.

In the second experiment, as in the previous framework, the idea was to explore the notion of contrast. He did so just by having one longer stroke that would map to a "melody" (the sequence of notes in the chromatic scale) and three punctual strokes that would generate background sound. As such, the contrast was between fast and slow change in the sound output, and in the visual display between point and line.

4.3.5. *Albers'sDissonances*

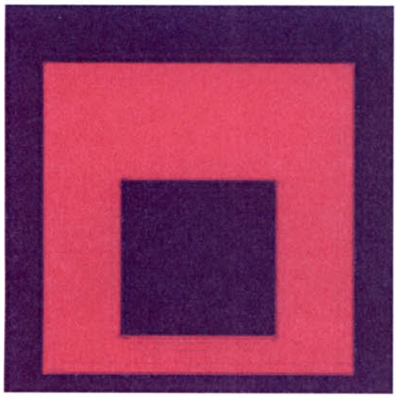

Figure 76. Panos's composition in *Albers's Dissonances* with sound off.

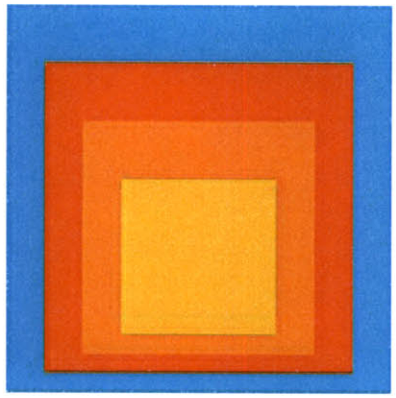

Figure 77. Panos's composition in *Albers's Dissonances* with sound on.

In the first experiment, the idea was to deny the geometry suggested by Albers in *Study for the Homage to the Square*. He did that simply by assigning the same color to the two middle squares.

In the second experiment, Panos was mainly concerned about the ending of the music sequence. It seemed too obvious for him that the sequence would end the same way it started: with consonant interval. Therefore, to mark the ending he just placed a contrasting color that mapped to a somewhat dissonant interval.

4.3.6. *Final Comments*

Like Rita, Panos picked *VisualScores* as being the most meaningful framework among all for the same reasons: more control over both the visual and musical composition, and the way he perceives the visual composition is in accordance with the mapping of the visual data to the sound data (which is based on the idea of the timeline).

However, Panos also felt that both *KandinskyLines* and *RecursiveRhythm* were interesting within the scope of this thesis in the sense that they produced somewhat unexpected results, leading the user to think about other forms of composing and especially other forms of perceiving what he sees.

4.4. First Test Subject with Musical Background

4.4.1. *VisualScores*

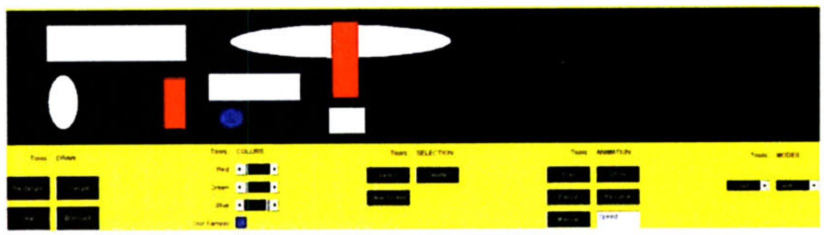

Figure 78. John's composition in *VisualScores* with sound off.

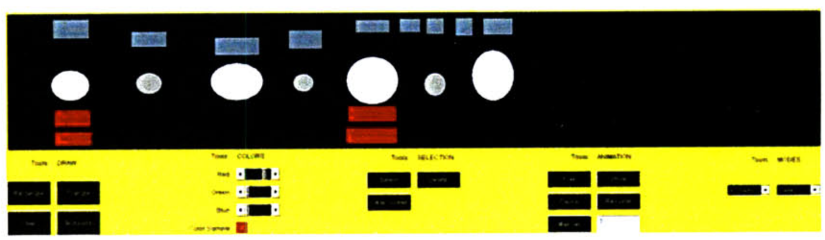

Figure 79. John's composition in *VisualScores* with sound on.

John is a computer scientist with musical background, and on top of that he also has some design background. In the first experiment, much like Rita, he tried to explore the framework by creating an abstract composition. He basically used the axes and lines defined by the geometric shapes (symmetry axes, boundaries, etc) to generate alignments and other relations (Figure 78) between the shapes. He too used horizontally stretched shapes in the hope that they would produce continuous sound.

In the second experiment, his idea was first to establish some structure and order, both visually and musically, by setting up a rhythm with the percussion (ovals) and the piano (red rectangles), and then, to play with the melody in the treble section (gray rectangles on top). The melody follows rigorously the rhythm defined by the bass section. As shown on Figure 79, there is a clear beat defined and the notes of different sections occur either on the beat, or at half way through in-between beats. So, for John, it was clear that simplicity and order were necessary in order to create musical structure. At the same time, he also worried about the visual aesthetics not only in terms of geometric layout but also in what concerns the use of color. This was also done by using simplicity and order; he used consistently white, gray, and red repeatedly according to the structure defined by the rhythm.

4.4.2. *KandinskyLines*

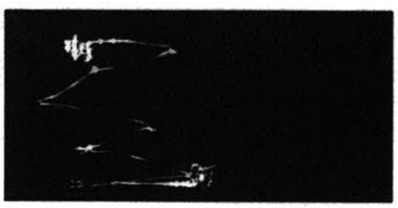

Figure 80. John's composition in *KandinskyLines* with sound off.

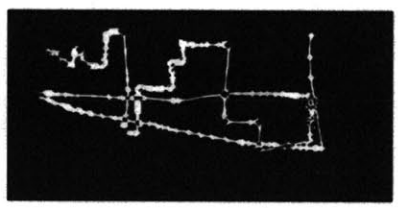

Figure 81. John's composition in *KandinskyLines* with sound on.

The first experiment consisted of an abstract composition in which the idea was to have two areas with considerable visual weight (on the top left and on the bottom right) connected by (almost) weightless elements (the long and narrow section of the lines).

The second experiment again showed John's worry about creating structure and order and from there generating a musical sequence. As shown on Figure 81, the line drawn is organized in steps (and the lengths of those steps are multiples of one another) that set up a rhythm; at the same time, each step (horizontal lines) maps to one note only which makes the melody built upon a limited number of notes and therefore contributes for the simplicity and clarity of the whole sequence. John worried as well about the ending: the vertical line on the left-hand side of the display marks the end by producing sequentially higher pitch notes that contrast with the low diagonal across the screen.

4.4.3. *RecursiveRhythm*

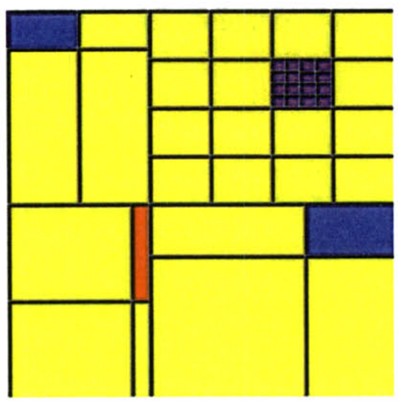

Figure 82. John's composition in *RecursiveRhythm* with sound off.

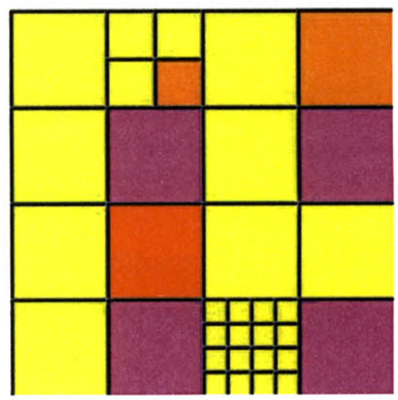

Figure 83. John's composition in *RecursiveRhythm* with sound on.

With *RecursiveRhythm*, John was first trying to get a balanced composition by assigning darker colors to some of the rectangles. Once he heard what that composition sounded like, he realized that it had no musical structure whatsoever.

In the second experiment, as opposed to Panos and Rita, John searched for a simple structure. He noticed that in *RecursiveRhythm* one can lose control over the musical composition easily, especially if changes to the proportions of the default shapes are made. Consequently, he opted to create a repetitive and controlled structure (a four-by-four array of squares) and build slight geometric and color variations on this theme: by dividing two of the squares recursively into more squares and by assigning different colors strategically to some of the squares.

4.4.4. *SchoenbergScribbler*

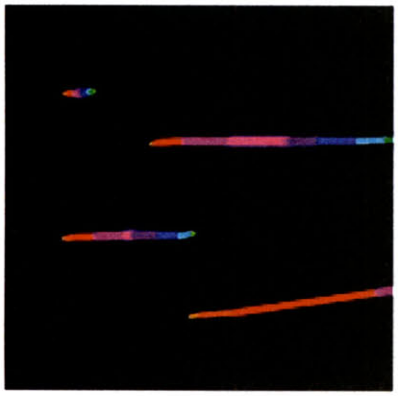

Figure 84. John's composition in *SchoenbergScribbler* with sound off.

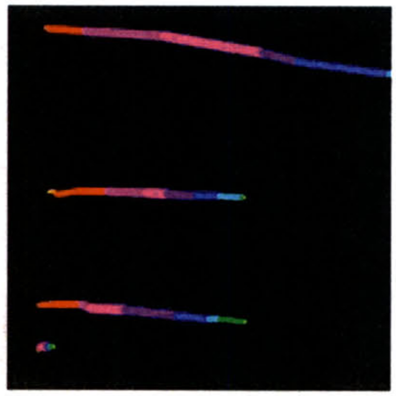

Figure 85. John's composition in *SchoenbergScribbler* with sound on.

In the first experiment with *SchoenbergScribbler*, John expected the mapping to be based on the musical scores: the sound relative to each one of the strokes would be produced as the composition was read from left to right. Also, he expected that the length of each stroke would determine the duration of the relative sound played, which in a way is true, except that, as mentioned in the last chapter, each stroke maps to not just to one note but to the twelve notes in the chromatic scale. John drew four horizontal strokes with different sizes starting and ending at strategic places. His initial idea was to have them start in pairs at the same horizontal coordinate, and equally-spaced in the vertical direction. However, the interface did not offer enough control over the drawing of the strokes in order to achieve precisely what he wanted.

In his second experiment (Figure 85), after hearing what the first composition sounded like, he noticed that having a fast and varied high-pitch sequence (i.e. short strokes in the upper part of the display) is not interesting and can even be annoying to a listener. At the same time, he wanted to contrast fast variations of notes with slower ones. So he decided to create a dynamic background sound made of low-pitch notes (i.e. the short stroke at the bottom), and a melody consisting of a sequence of high-pitch notes played discretely (i.e. the long stroke at the top). The two strokes in between were meant to fill the musical space. From the graphical point of view, he tried to create a *decrescendo*, where the spacing between adjacent elements decreases as the elements get shorter.

4.4.5. *Albers'sDissonances*

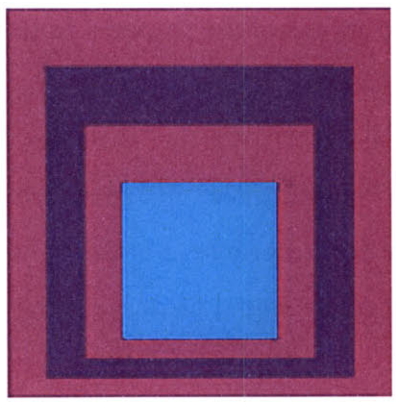

Figure 86. John's composition in *Albers'sDissonances* with sound off.

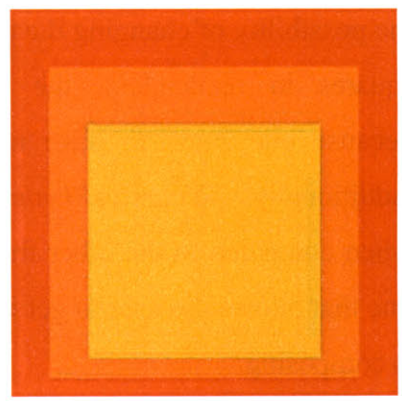

Figure 87. John's composition in *Albers'sDissonances* with sound on.

The idea for the composition showed in Figure 86 consisted of creating a pattern and breaking it at the end by assigning cyan to the smaller square. The reading that John made of Albers's geometry was opposite to that of the proposed framework: outside-in instead of inside-out.

In the second experiment, the idea was to have a sequence of consonances. However, he felt it was important to create some stability in the sequence. Therefore, he emphasized one note by having two sequential squares be of the same color, and, consequently, having one note played twice. This could be seen as setting the key for the melody.

4.4.6. *Final Comments*

John also chose *VisualScores* as the most significant framework in what concerns the relation between visual and audio, control over the variables, and control over the drawing gestures. For him, *RecursiveRhythm* required dealing with too many variables in order to have control over both the visual composition and the musical sequence. However, if one reduces the number of variables (he did that by not considering the possibility of changing the proportions of the shapes – from squares to rectangles), the framework gains significance because one starts to have real control over the variables. Additionally, *RecursiveRhythm*'s significance is increased when compared to the other frameworks because it is the only one that allows the user to get immediate sound feedback as he is composing.

SchoenbergScribbler also requires the handling of too many objects. For John, the framework would be much more meaningful if the user could only draw two strokes; which would be enough to create a significant amount of different visual and audio compositions. Also, he suggested that if the intention was to yield the idea of the randomness suggested by Pollock's paintings, maybe it would be worth creating a framework that suggests the idea of "jumping around". He felt that for the purpose of having each element vibrate individually, as it is, *SchoenbergScribbler* seems too rigid. Another problem with it, already mentioned above, is the fact that the user has little control over what he actually draws.

For John, having two or three variables is the limit in order to be able to create meaningful and controlled compositions; therefore, according to him, some of the frameworks would have to be simplified. *Albers'sDissonances* however worked well because within the limited number of possible compositions allowed, the user has full control over what he creates.

4.5. Second Test Subject with Musical Background

4.5.1. *VisualScores*

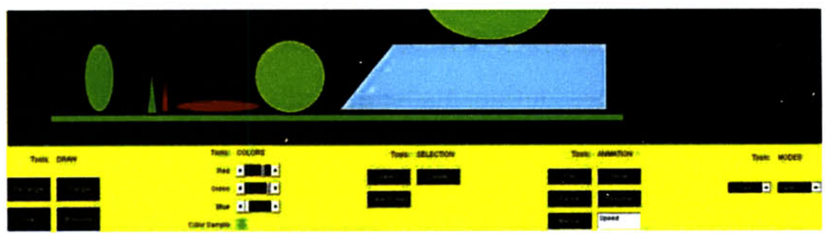

Figure 88. Pepe's composition in *VisualScores* with sound off.

Figure 89. Pepe's composition in *VisualScores* with sound off.

Pepe is a civil engineer with musical background. Although, as an engineer he is in fact a designer, he does not have thorough knowledge of visual arts, and hence, is not considered to be a subject with visual design background. In the first experiment, he drew a pictorial representation of existing things. The composition consists of a series of objects standing balanced on a scale. The scale is represented by a thin horizontal rectangle at the bottom. Pepe was trying to achieve balance by playing both with the sizes of the shapes and the colors. As such, it seems that the brightness and the large area of the cyan trapezoid on the right-hand side are compensated by the darkness of the small areas of the triangle and oval on the left-hand side.

In the second experiment, Pepe was not concerned with visual composition. He actually used the interface to compose a musical sequence. Although the composition shown in Figure 89 at first does not seem to be structured and ordered and it does not have a particularly appealing plasticity, it encodes a very structured melody. If one takes a more careful look at the image, it becomes clear that shapes have similar x-coordinates and that the vertical lines defined by the centers of gravity of the different shapes define mathematically related measures. Pepe used a third type of shape, the triangle that stands for flute sound. Pepe adjusted his composition several times before he got to the final result, a bit like testing musical ideas on the keys of a piano when a melody is being created.

4.5.2. *KandinskyLines*

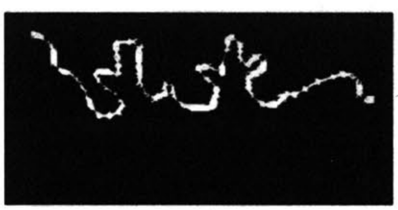

Figure 90. Pepe's composition in *KandinskyLines* with sound off.

Figure 91. Pepe's composition in *KandinskyLines* with sound on.

As in the first experiment with *VisualScores*, Pepe's composition consisted of a literal representation of something that exists in the physical world. In this case, his idea was to draw the skyline of a landscape in Mexico, in the style of a silhouette. From left to right, first there's a rock, then there are two cactuses and finally the far and hilly landscape. In terms of sound and musical structure, this sort of design did not make much sense, as it sounded quite chaotic.

His second experiment with *KandinskyLines* was metaphorically a dialogue between an older and a younger person. So the idea was to have the older person argue slowly and wisely (higher and thinner – less points and sections of the line) while the younger one would be talking very fast and complaining like a child (lower and thicker – more points and sections of the line). In terms of sound output, this design actually accomplished the initial intent. The concern with the visual composition once more did not exist. It was just a consequence of the design of the musical sequence. However, in this specific framework, since the x-coordinate does not influence the sound, several visual designs could produce the same audio design.

4.5.3. *RecursiveRhythm*

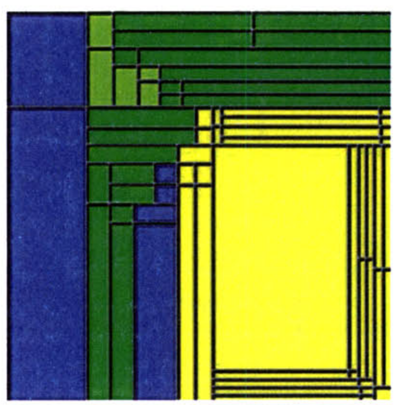

Figure 92. Pepe's composition in *RecursiveRhythm* with sound off.

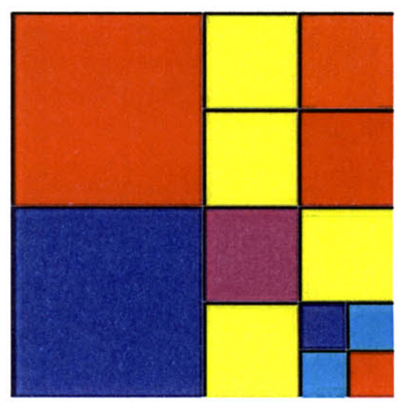

Figure 93. Pepe's composition in *RecursiveRhythm* with sound on.

Just as in the previous frameworks, the composition made for the first experiment with *RecursiveRhythm* consisted of a literal representation of real objects. Figure 92 shows a plan view of another landscape in Mexico. In this case, it is an Aztec pyramid by the ocean. The yellow rectangles represent the pyramid, the green ones the piece of land where it is standing, and the blue ones the ocean. Naturally, the resulting melody sounded much uncontrolled and with no structure whatsoever.

In the second experiment, like John, Pepe tried first to create a perceivable structure and then create variations on that. From the first experiment, he understood that if he were to create anything that sounded like music or at least had musical structure, he had to keep in mind that rhythmic divisions should not be too complex and that they should be accurately controlled. In this specific case, he tried to create a melody that sounded somewhat oriental. For this, he made the duration of the notes gradually smaller and then have them contrast with a comeback to initial more lasting notes.

4.5.4. *SchoenbergScribbler*

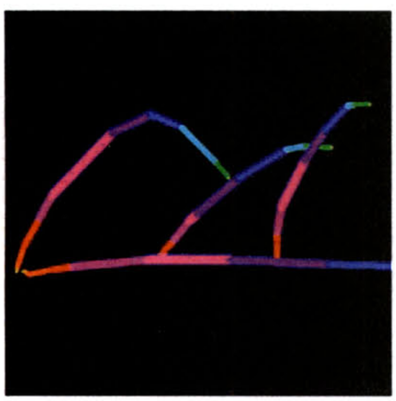

Figure 94. Pepe's composition in *SchoenbergScribbler* with sound off.

Figure 95. Pepe's composition in *SchoenbergScribbler* with sound on.

The composition made for the first experiment consists of a front view of mountains. In the second experiment, Pepe tried to explore the simultaneous generation of the notes in the chromatic scale in the same way John did. So he drew two short strokes in the lower part of the screen to set a fast background rhythm and the melody consisted of a slow sequence of the high-pitch notes in the scale defined by the two longer strokes.

4.5.5. *Albers'sDissonances*

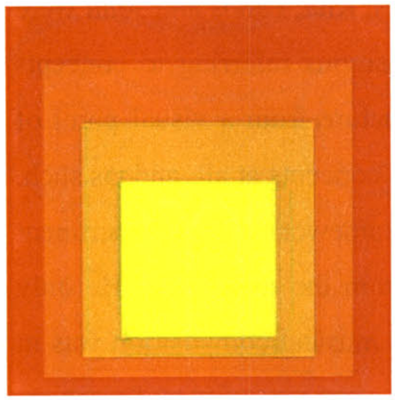

Figure 96. Pepe's composition in *Albers's Dissonances* with sound off

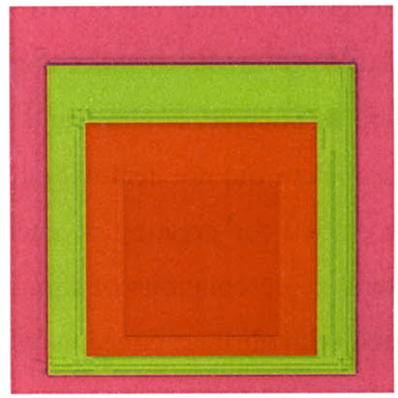

Figure 97. Pepe's composition in *Albers's Dissonances* with sound on

Using *Albers'sDissonances*, the first experiment consisted simply of creating a perspective view effect. In the second experiment, Pepe tried to create a composition that would map to the notes of a seventh chord. So, once again he did not care much for the final visual result. However, it's interesting to think of a framework that allows the user to see, in terms of colors, a chord. The note sequence was supposed to be: C-E-G-bB (half-tones: 4-3-3) and the sequence he came up with was C-F-G-#G (half-tones: 5-2-1). However, he acknowledged after hearing the sequence a few times that the notes were actually not the right ones and identified the actual ones.

4.5.6. *Final Comments*

For Pepe, and for the same reasons mentioned in the previous cases, the most meaningful framework within his own interest, not within this thesis's scope, was *VisualScores*. He felt that it was the one that provided more flexibility and control as a tool for musical composition. In his case, the frameworks were actually disregarded as tools for composing with multiple feedbacks.

The difference between subjects with and without design background stands out in two ways. Rita, Panos and John were all able to create abstract compositions referring to concepts such as balance, contrast and structure from a visual point of view. Pepe did not deal with these concepts at all, and, as such, he settled for creating in each framework's first experiment literal representations of things from the real world. He only dealt with abstract concepts when musical composition was in question.

Also, in the second experiment, all designers cared about creating meaningful compositions from both points of view, musical and visual, whereas Pepe disregarded completely the visual part. It seems that subjects with design background have a greater ability to take into consideration information coming from different sources at the same time.

5. Significance of the Frameworks

5.1. Supporting the Claim

5.1.1. *Comparative Analysis: First Experiment / Second Experiment*

In all four cases, the results of the second experiments yield common characteristics. In fact, as can be observed in Chapter 4, the presence of concepts taken from the field of music, (such as structure, rhythm, variation and melody) is enhanced in the second experiments. Although they are concepts closely related to music, they are also part of the field of design, and architecture in particular. Ultimately, musical feedback is a significant means to create meaningful visual designs, which is to say that multiple feedbacks support the efficiency of the design process altogether, leading to a potentially more creative and rigorous final object. The following examples show how the concepts taken from music can be crucial for architectural design.

- Structure and Melody:

In architecture, especially in façade design, the notions of rhythm (structure) and variation (melody) frequently define the overall image of a building. From classic to modern architecture, there are innumerable examples of buildings that explore the duality between repetition and variation.

Figure 98. Giovanni Battista Piranesi, Etching, *View of the Palazzo Farnese*, 1773.

Figure 98 shows an etching made by Piranesi of Antonio da Sangallo's Palazzo Farnese in Rome. Its façade is based on the repetition of one basic element – the window – in a two-dimensional array. However, this repetition is "animated" by slight variations made to the basic element both horizontally and vertically; horizontally because the windows in the middle row have alternatively a triangular fronton and a circular fronton, and vertically because each row has a specific type of window. In terms of mapping, the array and the actual instances of the windows are respectively the visual equivalent of the regular rhythm (i.e. the structure) and the actual instances of windows the sequence of notes (i.e. the melody).

In Gunnar Asplund's Villa Snellman (Figure 99), the same approach can be made. There are clear horizontal and vertical rhythms that define the overall structure and order of the façade, but there is not actually a constant and regular repetition of the basic element (which is also the window), firstly because the spacing between windows differs according to the row, and secondly because the top element on the second column, although also a window, is a different type of window. Once again structure and variation are the crucial concepts that rule the overall image of the façade.

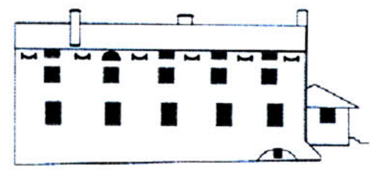

Figure 99. Gunnar Asplund, Villa Snellman, Djursholm, 1918.

In the case of the Pompidou Center (Figure 100), this duality is even clearer. The (literal) structure defines the background and the diagonal line (i.e. the escalators) defines the foreground. Variation occurs as the line moves freely within the overall structure defined by the grid.

Figure 100. Richard Rogers and Renzo Piano, Pompidou Center, Paris, 1976.

These three examples show that architectural design can be based upon concepts and ideas that are not exclusively architectural (in fact, being architectural design a synthesis of multiple disciplines, it is hard to think exclusively about architecture as an independent field of study). The frameworks proposed in this research support this by using music as means to generate design and to think about design. However, other concepts from other disciplines such as civil engineering (Figure 101), mathematics (Figure 102), or urbanism (Figure 103) can contribute just as much for the creativity and the significance of the design process and the final design object.

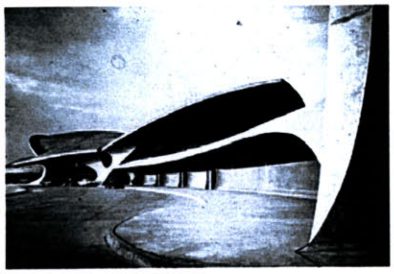

Figure 101. Eero Saarinen, TWA Terminal, New York, 1962.

Figure 102. Le Corbusier, Philips Pavilion, Brussels, 1958.

Figure 103. Le Corbusier, Plan Voisin, 1925.

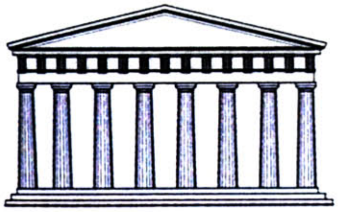

Figure 104. The Parthenon, Athens.

- Beginning and Ending

The second experiments described in Chapter 4 (i.e. the ones with the sound on) show that the users frequently worry about creating a beginning and an ending in their composition. This seems natural as most musical sequences have a prelude and a finale of some sort. What is noteworthy about the experiments is the fact that the test subjects felt that the musical sequence (in general) would not be complete without an introduction and a conclusion, and therefore their visual composition reflected that as well.

Although prelude and finale are words that are related to the field of music, there are equivalent words in the architectural language, which means that the very concepts of introduction and conclusion are meaningful within architectural design. Looking at the concrete example of the Parthenon (Figure 104), it becomes clear that almost all architectural elements, in smaller and larger scales, are conceived as junctions of components. In a way those components correspond to the concepts of introduction, body, and conclusion. For example, the Parthenon is composed of base (i.e. beginning), columns (i.e. body) and pediment (i.e. ending).

Although some modern architecture tends to deny canons, rules and orders, there are some basic concepts that do not have to do with specific styles but with the overall art itself. Composing in a structured way is one of them. Rafael Moneo's Murcia Town Hall (Figure 105) shows that the use of introduction-body-conclusion in architecture is still a valid and potentially creative way to structure the overall design of a building. As the image shows, there is a starting point (at the bottom: essentially solid), a body of forms progressing and an ending point (at the top: essentially voids).

As in the last point (concerning structure and melody), the frameworks allow the user to compose visually taking into consideration concepts that may be more naturally perceived in other fields (in this case, music), and that may be valuable to the specific activity of design.

Again, dual (i.e. multiple) feedback(s) may contribute for the meaningfulness of a design.

After analyzing the experiments with sound, it seems that the compositions resulting from the experiments without sound tend to lack a perceivable order and to be solely intuitive. The second ones tend to express the subject's intuition within a pre-defined structured framework, which contributes for a more rigorous, varied and mature way of designing.

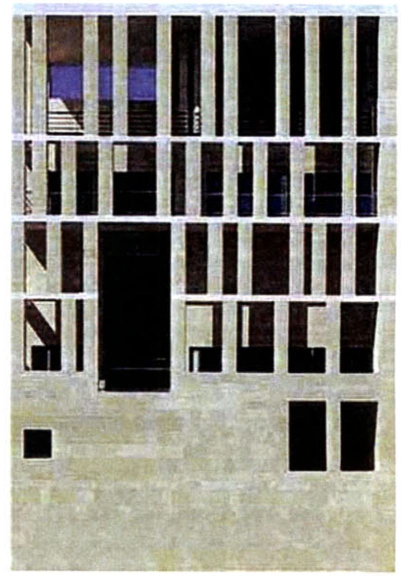

Figure 105. Rafael Moneo, Murcia Town Hall, Spain, 1998.

5.1.2. *Comparative Analysis: Subjects with Design Background / Subjects with Musical Background*

From the results of the experiments made in Chapter 4, several conclusions can be drawn regarding the pros and cons of having a design background versus having a musical background in the context proposed by this investigation. Essentially, it seems more natural for designers than musicians to deal with multiple representations. Moreover, designers seem to be able to compose taking into consideration the abstract concepts pertaining to both visual and sound media referred above. In fact, Pepe's first experiment showed that he could not create abstract compositions, just literal representations of the physical world, and the visual part of the composition was literally forsaken in his second experiment.

However, subjects with musical background do stand out in a way that the designers do not. On the one hand, both John and Pepe seemed to be extremely concerned with the exact sound output, which contributed for overall more rigorous compositions. On the other hand, their compositions tended to be simpler than those of the designers, which made them especially controlled and consequently meaningful.

5.2. Frameworks as Independent Objects

5.2.1. *Objects along the Way of Studying the Design Process*

The design process, and particularly the architectural design process, implies the creation of objects that, on the one hand, are intermediate entities through which the designer builds a critique upon his own thoughts and ideas, and on the other hand, may generate creative thinking. These objects are essential for the design process to evolve. In the particular case of architectural design, they can be sketches, drawings, models, narratives, etc. William Porter refers to them as "objects along the way of design"[14]. Just as much as the final object at which the design process aims, these objects "can assume the full significance of any object. They can embody, symbolize, and mean in ways that are identical to the cultural artifacts we identify as buildings or paintings or other "finished" works" [15]. For example, Figure 106 shows a sketch made by Alvaro Siza when he was working on the Malagueira housing project in Évora, Portugal. Naturally, these sketches are aiming at representing the author's ideas for the final design of the project. However, they are also aesthetical entities that express the author's worries and ideas at the time they were built. One might compare these sketches to cubist paintings (Figure 107) as they express different aspects of one three-dimensional object (non-existing yet at that point) on a two-dimensional medium. In other words, like Picasso's *Weeping Woman*, they

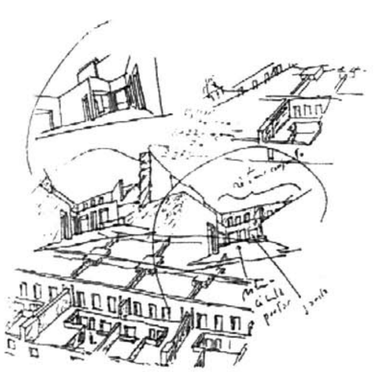

Figure 106. Alvaro Siza, sketch for the Malagueira housing project, Evora, Portugal, 1978.

are visual representations of time; and this contributes to their own significance as independent objects and not solely to the final design for the Malagueira project.

Both Carlo Scarpa and Frank Gehry have produced in their practice exceptionally meaningful design objects. Figure 108 shows a sketch plan of the design of the monument to the Partigiana by Carlo Scarpa. Although it is in fact a plan, a viewer can disregard that information and just criticize it as an abstract composition of forms that represents independent ideas such as deconstruction or cooperation. Frank Gehry's model representing an evolving design for the Telluride Residence can also be disregarded as such and just be considered as a sculpture that explores the relation of solids and voids through the use of organic forms (Figure 109).

In scientific research, different types of models (computational, mechanical, physical, etc) are built in order to support some claim. These models can be compared to the independent objects created along the way of design because they can be meaningful outside their intended field of application. In many cases, they end up having a short run and a long run impact: they are useful in the specific research they were built for, but also in other unrelated fields that might not have even existed at the time. For example, the internet, commonly used today by people in almost every field as a means of communication or just a leisure tool, was initially developed by the US Department of Defense as an internal computer network system that made information-handling more space and time-efficient. Also, the parametric design software Catia started off as a tool for the design of military airplanes by the French firm Dassault Systemes, and it soon spread to other design fields such as car design, industrial design and architecture.

Figure 107. Pablo Picasso, *Weeping Woman*, 1937.

Figure 108. Carlo Scarpa, sketch for the monument to the Partigiana, Venice, Italy 1968.

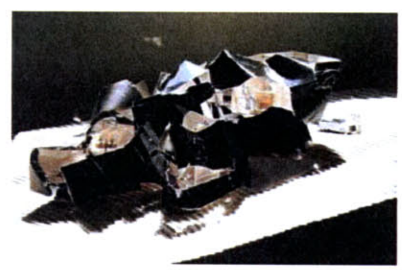

Figure 109. Frank Gehry, concept model for the Telluride Residence, 1989-95.

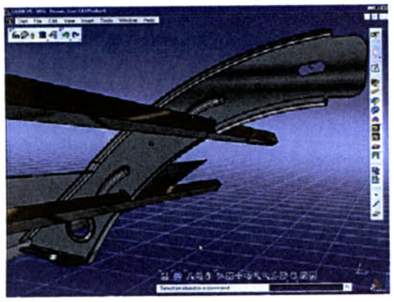

Figure 110. Aerospace sheetmetal design Catia model.

Figure 111. Frank Gehry, Stata Center Catia model.

These models may be considered as objects along the way of research.

The initial and general topic of this thesis is the study of the design process. Just as in design activity, several objects aiming at a final purpose were created, except not along the way of design, but along the way of studying the design process or along the way of research. These objects are the mapping frameworks described in Chapter 3. Initially, they were created as computational and cognitive models to support a research claim. However, they are more than mere demonstration tools, they are fully significant and independent audio-visual interfaces that express through their structure the (initial) objective of this research but also engage the user into different and unexpected worlds. The following sections describe what some of those worlds might be.

5.2.2. *Design Media*

Regardless of what they were originally intended for, the five frameworks proposed in this investigation are design media that support the creation of audio-visual compositions. The relationship between visual data and sound data is actually the basis for an active research field that studies the translation of information from one medium to the other. People in the former *Aesthetics & Computation Group* and the *Hyperinstruments Group* at the MIT Media Lab have developed research projects on the this topic. In his Master of Science in Media Arts and Sciences thesis *Painterly Interfaces for Audiovisual Performance*, Golan Levin proposes a series of frameworks, namely *Loom*, that exemplify "a new computer interface metaphor for the real-time and simultaneous performance of dynamic imagery and sound"[16]. The metaphor's main idea consists of the simultaneous mapping of gesture to graphics and sound. In *Loom*, speed, direction and pressure are the characteristics of the user's gestures that map to an audiovisual output. The paintstrokes' widths depend on both the pressure and the speed of the gesture. Using frequency modulation, the sound is then produced from the information encoded in the strokes (width maps to amplitude and local curvature maps to the FM index), which makes the mapping rules based on low-level variables.

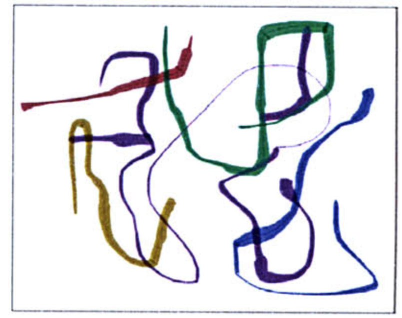

Figure 112. Golan Levin, a composition using *Loom*.

As mentioned in chapter 3, the contributions of the audiovisual frameworks proposed in this research are based on higher level concepts such as visual perception and cognition. The frameworks attempt to make people's metaphorical perception of visual data concrete by means of the sound medium. So, on the one hand, they are tools that support specific design activity: unlike an empty canvas, the user does not have total freedom in the way he expresses his creativity. He has to compose within the framework's set of composing rules and constraints; the positive aspect of having constraints beforehand is that a structure already exists, and that may trigger ideas or thoughts that otherwise would not emerge. On the other hand, they are instruments that make the user think about the meaning of abstract compositions: whether he does or does not accept the mapping rules of the frameworks, he will necessarily reflect upon the translation of graphics into sound/music, and by doing that he will refer to specific concepts of abstraction such as structure, variation, contrast, balance, dialogue, etc. Consequently, the proposed frameworks stand out as design-oriented pedagogical tools.

5.2.3. *Design Cognition Media*

The objects created along the way of this research, as stated in the last section, are media in which users design. In this section, I will explain why they are also media in which users think about design and its nature.

In *Mindstorms*, Seymour Papert explains why people have problems in learning mathematics and tend to be what he refers to as mathofobic. For him, the degree to which learning *something* is problematic or not has to do with how embedded that *something* is in the involving culture. For example, a child that lives normally in some society has no problem whatsoever learning the dominant language in that society. However, children usually have a hard time understanding mathematics. And according to Papert, it has to do with the fact that we do not live in a math culture. Children do not really experience mathematics the way they experience communication: they are taught mathematics, whereas they are both communicative beings and taught how to communicate.

To a certain degree, the same reasoning can be applied to music and visual arts. In western culture, people in general are much more exposed to music than they are to the visual arts. One might argue that people are constantly exposed to architecture, but not every building can be considered architecture; in fact, most of what is being built in cities nowadays does not go beyond the denomination of construction. In the case of music, for better or for worse, people are in fact constantly exposed to it; even, the most basic pop songs are built upon a certain structure and theory.

Therefore, from an early age, people tend to get familiar with basic and intuitive music concepts (such as rhythm, consonance, volume, etc) whereas their knowledge of the visual arts is somewhat reduced. Nevertheless, the concepts referred to are not specific to music. They are concepts that are constantly used in design education by innumerable schools namely the Bauhaus in the early twentieth century. So, by getting a musical feedback, a user automatically associates important concepts to the visual composition. He necessarily thinks about concepts that are fundamental in design activity and therefore thinks about the nature of design.

In the first chapter of *Mindstorms*, "Computers and Computer Cultures", Seymour Papert states:

> In the LOGO[17] environment the relationship is reversed: The child, even at preschool ages, is in control: The Child programs the computer. And in teaching the computer how to think, children embark on an exploration about how they themselves think. The experience can be heady: Thinking about thinking turns the child into an epistemologist, an experience not even shared by most adults.[18]

Epistemology studies the nature of knowledge, therefore a child gains expertise in dealing with knowledge, which means that he actually learns knowledge and learns how to organize and structure that knowledge: he learns how to think.

As mentioned above, by using a framework, one inevitably thinks about the nature of design. If we draw a parallel between general education and design education, then a user of the frameworks gains expertise in dealing with design concepts, and therefore not only learns the essence of those concepts but also learns how to relate those concepts to each other. And at a high-level that is what design consists of.

So, by thinking about design, one is inevitably embarking on a learning process: the process of learning how to design.

5.2.4. *Design Education*

The very nature of the proposed computational frameworks turns them into objects that are likely to have a positive impact on general design education strategies. The following characteristics make them particularly significant as pedagogical objects for design students:

- Immediate feedback:

Modern education researchers claim that passive learning makes learning non-efficient and painful. If children have the opportunity to deal from within interactively with the concepts that traditionally are taught in lecture format, they will not only have more fun but will learn faster and better. According to Piaget, interactivity supports the learning process. Seymour Papert says:

> I have previously spoken of "Piagetian learning", the natural, spontaneous learning of people in interaction with their environment, and contrasted it with the curriculum-driven learning characteristics of traditional schools.[19]

As interactive tools, computers yield radically different ways of approaching education in general and are particularly well-suited to support this type of learning. Because the frameworks here proposed provide (almost) immediate feedback, (one can hear his composition as he is composing), they are in accordance with Piaget's position regarding interactivity.

- Design concepts:

In a somewhat simpler way, a user deals from the start with basic concepts that are fundamental to design activities. Some of these concepts have been mentioned in the previous section of this chapter and in the previous chapter: abstraction, structure, and metaphorical thinking. For an inexperienced design student, the possibility of exploring these concepts in a much simpler context than the actual architectural context is a valuable asset at an initial stage.

- Multiple variables:

Design activities and architectural design in particular imply the control of numerous variables in relation to each other. An optimal design is achieved somewhat like an unstable equilibrium: by carefully juggling with different elements. As such, a designer needs specific skills that allow him to cope with these different elements in order to reach a common objective. These skills are acquired gradually and, in order to learn how to deal with multiple variables, one should start off by controlling a reduced number of variables.

The proposed frameworks yield the handling of multiple variables and, since they do not imply the control of as many variables as the actual architectural design process, they are potentially good tools for developing the skills referred to above.

- Critique:

Being able to build sensible critiques is a powerful endowment for designers because it allows them to make optimizing choices during the design process. Thus, design education in general privileges the development of a critical mind over the ability to produce designed artifacts. Having both graphical and musical feedback makes the frameworks potential contributors for supporting this type of educational strategy. In fact, musical-and-graphical feedback forces explicitly the user to build an evaluation on his design. An unpleasant melody has a direct and profound impact on the listener and cannot be perceptually avoided, whereas a visual composition alone can more easily be disregarded.

- Being a designer:

By using these programs, one not only simulates design activity but produces it. This contributes for a more in-depth understanding of the underlying structure of design.

According to Seymour Papert, a natural way in which children learn is by bringing previous knowledge into unfamiliar domains:

> Children can *identify* with the Turtle and are thus able to bring their knowledge about their bodies and the way they move into the work of learning formal geometry.[20]

As mentioned in Chapter 3, when composing in one of the proposed frameworks, one does it by means of metaphors that relate musical structure and graphics. Like Turtle Geometry, a user brings previous acquired musical knowledge into the work of learning design, and by doing so learns about design in a more natural form.

- Debugging:

For Seymour Papert, a serious educational strategy does not lie on the evaluation of a student based on the correctness or incorrectness of his final solution to a problem. Promoting heuristics in problem-solving should be an important part of education policy. According to him, computer programming is valuable in that sense because it forces the programmer to develop debugging strategies (which consist of logical and effective ways to fix problems step-by-step) that ultimately contribute for rigor in problem-solving.

> (…) when you learn to program a computer you almost never get it right the first time. (…) The question to ask is not whether it is right or wrong, but if it is fixable.[21]

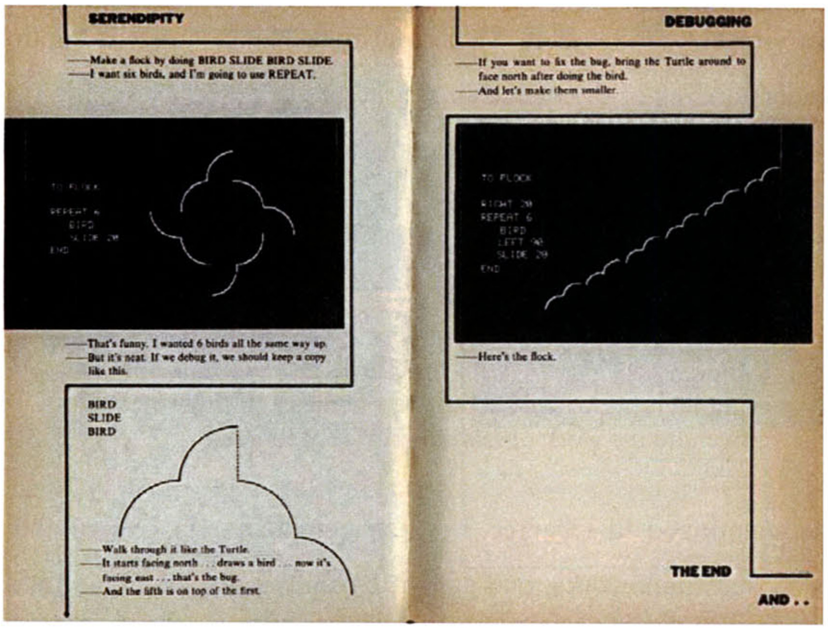

Figure 113. Seymour Papert, *Mindstorms*, trial-and-error using LOGO.

Although the composing environments are not programming environments, they both have in common the fact that the user also gains control over what he composes by trial-and-error. In fact, as the experiments in Chapter 4 show, before they actually achieved a satisfying composition, all the users had to get to know the underlying structure of the frameworks through several trials. In a way, they had to debug their composition, and by doing it, they necessarily had to think of better ways to organize the variables in regard to design concepts. Ultimately, they gained experience in design thinking.

5.3. Reviewing the Frameworks' Designs

5.3.1. *As Tools for Composing and Design Education*

In what concerns composing and design education, the flaws revealed by the use of these tools during the experiments made in Chapter 4 consist mainly of issues related to the user interface:

- The number of variables that require control over is too large, especially in *RecursiveRhythm* and *SchoenbergScribbler*. By decreasing that number, they would gradually become more significant, both for composing and for learning. In fact, the user would be more conscious about his choices which would yield more controlled compositions. Furthermore, when one is at a learning stage, it is important to start with simple problems, and by reducing the number of variables, the design problems at hand would become more adequate for pedagogical purposes.
- As mentioned previously, debugging and trial-and-error are essential concepts for education purposes. In terms of user interface, one way of supporting this is by having the *undo* and *redo* options that allow a user to test, compare and go back to previous designs. Moreover, it turns the overall framework more user-friendly for composing in general.
- Compositions in the frameworks that require stroking (*KandinskyLines* and *SchoenbergScribbler*) turned out to be difficult to control. In fact, it is almost impossible to obtain the exact length or width that the user intends to obtain. Once again, if the control over the strokes could be as accurate as the control over the gestures made for producing the strokes, both composing and learning would become more meaningful.

5.3.2. *As Tools for Mapping Visual Data to Sound*

The experiments on the test subjects revealed several flaws in what concerns the mapping from visual to sound. The following points suggest how the frameworks could be improved in that sense:

- The use of color could have been further developed in most of the frameworks. The only one that truly deals with the meaning of color is *Albers'sDissonances*. Whereas the remaining four used color in the mapping process arbitrarily (some people claim that color can be related to sound by means of frequency, but there is not actually a strong reason supported by human perception for doing that) *Albers'sDissonances* approaches the use of color by means of relations. In music, a single note played is meaningless. It becomes significant when it establishes relationships with other notes: an interval is the smallest meaningful element. Therefore, one way of actually relating colors to sound is by considering the proximity of colors in the color wheel as the smallest meaningful element and turning it into the object of the mapping framework. Naturally, there are other forms of establishing relationships between colors: by contrast, by type (e.g. pastel colors), etc. As such, the first four frameworks would probably benefit (in the sense that the mapping rules would seem more obvious to a first-time user) if the mapping of colors were treated in the same way as in *Albers'sDissonances*.
- In their first trial in *VisualScores*, all the subjects drew horizontally stretched shapes in the hope that they would map to a continuous sound, somewhat like the line in *KandinskyLines*. The idea of having each shape concentrated on its center of gravity for the purpose of producing sound does not make much sense from a perception point of view. It would

have actually been a more natural framework if the duration of the note relative to each shape depended mainly on the length of that shape.

- In *Albers'sDissonances*, the sound produced by a composition is a linear sequence of four notes and the graphics do not actually suggest that very idea of line. By introducing other variables such as volume or duration of notes, instead of suggesting the idea of a line, the audio output could give the user a more spatial and non-linear perception of the composition altogether.

6. Conclusion

6.1. Concluding Remarks

The study of the design process, and the search for ways through which it can be improved constitute the original basis for this thesis. However, the design and implementation of the mapping frameworks as a means to support the initial claim suggested other exploration possibilities, namely the use of computation in design education. In the 1980's, Seymour Papert had already foreseen the potential of computation in general education. Design education can also benefit from computation: flaws difficult to overcome with traditional pedagogical methods (such as lack of interactivity or immediate feedback) can be diminished through the use of computers. I believe that computers can and should play a gradually increasing role in design schools, not just as drawing tools, or even design tools, but as means to explore the basic design concepts and especially new concepts related the very existence of computers themselves, i.e. as tools to learn about design theory and design thinking.

6.2. Future Directions

The proposed frameworks in this thesis still stand at an extremely primitive stage, both as a medium in which a user can generate audio-visual compositions and as a medium oriented toward design education. In what concerns the former, the following topics constitute potential areas for improvement:

- Traditional media, such as pencils and paintbrushes, or musical instruments, have been used and developed for centuries, so their performance as media that express a person's thoughts and ideas has been optimized. Computers, however, have only existed for a half century, and, more specifically, computers as art media, even less than that. Issues concerning user interfaces still have to be explored more thoroughly so that computation can actually be meaningful for artistic expression. One way of approaching this problem is through the study of Tangible User Interfaces as tools that support creativity. The *Tangible Media Group* at the MIT Media Lab has worked on several projects that do support the expression of creative thinking. For example, *Illuminating Clay* offers architects and planners the possibility to view in real-time their physical models in a virtual environment (Figure 114).

Figure 114. *Illuminating Clay*, Tangible Media Group, MIT Media Lab.

- Strengthen the link between musical and actual architectural design. Ray Bennett, who was awarded the 2002 AudoDesk iDesign award, proposed a system that translates audio information into three-dimensional compositions of shapes (Figure 115). His idea was to see what musical compositions could look like. Thus, he developed an algorithm that mapped music variables to architecture variables: time to the x-position, pitch to the z-position and the place of the instrument within the orchestra to the y-position. However it seems that an important aspect that is lacking for a mapping between music and architecture to be meaningful, both in Ray Bennett's algorithm and in this thesis's audio-visual frameworks, is the place that architectural meaning takes. How can Function be taken into consideration in these types of mapping frameworks?

Figure 115. Ray Bennett, Architectural Interpretation of Music.

Regarding design education, the frameworks' characteristics referred in chapter 5 can be explored in alternative ways in order to make the frameworks more effective from an educational point of view. The Bauhaus was particularly dedicated to design education through the exploration of abstract concepts. The ideas conveyed in the pedagogical textbooks by Paul Klee, Wassily Kandinsky and Johannes Itten, among others, could be of value for the design of computational algorithms in frameworks that support pedagogy in design.

Sources of Illustrations

All the illustrations are by the author, unless otherwise indicated.

Figure 1.
"4.273 - Introduction to Design Inquiry" archive (StudioMIT).

Figure 2.
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Figure 3.
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Figure 7.
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Figure 8.
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Figure 9.
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Figure 20.
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Figure 21.
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Figure 102.
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Figure 104.
Mitchell, 89

Figure 105.
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Figure 113.
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16. Golan Levin, Painterly Interfaces for Audiovisual Performance, Master of Science in Media Arts and Sciences Thesis (Cambridge, MA: MIT Media Laboratory, 2000), 3.

17. LOGO is a programming language used for defining the movement of a Turtle, which is an entity that has a position and faces a direction. It can move, rotate and leave its movement's trace on the computer screen creating thus graphical outputs. It has been widely used in schools as a tool for learning geometry.

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