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Santa Barbara

Archimusic, A New Poïesis: A Method for Archimusical Synthesis

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Media Arts and Technology

by

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January 2018

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To those who endeavor to make a more beautiful world.

Acknowledgements

Guidance, Insight, & Deepest Thanks

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Architecture and Biometrics

"Art, and, above all, music has a fundamental function, which is to catalyze the sublimation that it can bring about through all means of expression. It must aim through fixations, which are landmarks to draw towards a total exaltation in which the individual mingles, losing his consciousness in a truth immediate, rare, enormous, and perfect. If a work of art succeeds in this undertaking even for a single moment, it attains its goal. This tremendous truth is not made of objects, emotions, or sensations; it is beyond these, as Beethoven's Seventh Symphony is beyond music. This is why art can lead to realms that religion still occupies for some people."

- Iannis Xenakis

ABSTRACT

Archimusic, A New Poïesis:

A Method for Archimusical Synthesis

by

Francesco Myles Sciotto

In 1958, the 20th-century architect and composer Iannis Xenakis transformed lines of glissandi from the graphic notation of Metastasis into the ruled surfaces of nine concrete hyperbolic parabolas of the Philips Pavilion. Over the next 20 years, Xenakis developed the Polytopes, multimodal sites composed of sound and light, and in 1978 his Diatope bookended these spectacles and once again transformed the architectural and musical modalities using a general morphology. These poetic compositions were both architecture and music simultaneously; forming the best examples of what Marcos Novak would later coin as "*archimusic*." Contemporary examples have continued to experiment with this interdisciplinary domain, and, although creative and engaging, the outcomes have yet to yield results that move this transformational conversation forward.

This dissertation examines how to advance this transformational field of *archimusic* by introducing: (A) *a knowledge resource*, which collects and categorizes important *archimusic* practitioners and projects (*Archimusic Repository*), (B) *an evaluative method* to analyze the trans-disciplinary works of *archimusic* (*Archimusical Transmodal Matrix*), and (C) *a generative system* which integrates new digital modalities into the transformational compositional process (*Kosmos*). Together these three contributions categorize the field of *archimusic* as an end in itself, presenting the trans-disciplinary territory of *archimusic* as a studied and understood discipline framed for continued exploration and aims to contribute a novel way of thinking and making within this dynamic spatial and temporal territory.

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Foreword

This research and dissertation presents an introduction to the topic of *archimusic*, a background and thorough history of the works and methods that have laid the foundation of *archimusic*, and the tools and processes that form a contemporary appreciation and understanding of the topic. Most importantly, this research aims to frame the field of *archimusic* as an end in itself and to encourage the continued thinking and making within this trans-disciplinary field.

This research challenges the traditional methods used within the field and encourages the disciplines of architecture and music to focus on new and unique integrations. I have selectively chosen historical works from both disciplines that exemplify and promote this engagement and these integrations. By no means do these examples represent the whole of knowledge on the subject matter and there will surely be other examples that fit into this study. In this manner, this research approaches, and asks the readers to also approach these perspectives as a both/and method of inclusion.

It is the intention of this research to be of interest to students and researchers of both undergraduate and graduate levels in both architecture and music, though there will be an inherent bias towards the architectural subject matter, as it is the principle discipline of my education, practice, and approach to the research questions. It is also the intention of this dissertation to be of interest and digestible to the general public, and, to this end, I have aimed to write this dissertation without using esoteric terminology or jargon. However, there are a number of specific terms and definitions that will be utilized and therefore need to be understood. Many of these terms will be introduced in the following few sections, and all terms are listed in the glossary portion of the appendix at the end of this dissertation for reference.

It is my sincere belief that this research will advance the *archimusical* practice of trans-disciplinary thinking, and multimodal approaches to making; helping to bring together artistic hybrids towards the building of a future rich in artistic and cultural content — pushing the realm of ideas forward.

1. Introduction

"It is perfectly true that music and architecture flower from the same stem."
~ Frank Lloyd Wright (Wright F. L., 1992)

Throughout time, architecture and music have found inspiration and direction in each other and their respective creative and technical processes; each seeking beauty, structure and unity in the ways that the other is composed, drawn, written, heard and built. As architecture can be understood as the purest of the spatial arts, so can music be referred to as the purest of the temporal arts (Bragdon, 2005) and together these two fields have developed intimate integrated relationships with one another. During heightened times of cultural advancement, architectural and musical works that have engaged one another have created some of humanity's most celebrated works. Works that intimately fuse these two disciplines are called *Archimusic*, and this dissertation is concerned with the advancement of this trans-disciplinary field.

The term *archimusic* was coined by *Marcos Novak* (Novak M., 1992), defined as "*a place where buildings can flow and music can be inhabited. When this is understood, the distinction between architecture and music can be set aside…therefore, I will refer to the combination of architecture and music with a new term, archimusic. As the name implies this is the art and science that results from the conflation of architecture and* *music.*". *Archimusical works* use, embed and/or inform an element of its own composition or process with an attribute or characteristic from the other discipline. For example, a work of music that is informed by an architectural work, or the opposite; an architectural work that is informed by a musical work.

The relationships between architecture and music evolved over time, each advancing the methods in which architectural and musical works were related to one another. The *ancient* relationships between architecture and music were *associational* in nature, where architectural and musical works were both created by means of another modality often relating to the mathematical, geometric, musical, or cosmological understandings of what became the *Quadrivium,* part of the classically-inspired seven liberal arts (the other part being the *Trivium* (grammar, rhetoric, and logic)). During the *Renaissance*, constructed and composed works began evolving from associational relationships into *translational* interpretations. This advancement was achieved by taking a piece of music or a work of architecture and translating a component of it into the other discipline. During the *modern* period of the mid-20th century, these translational interpretations evolved to become *transformational* integrations by using methods and practices found in one modality and integrating them into their own respective process and generation. The works of the Greek architect and composer *Iannis Xenakis* represent many of the most important transformational integrations achieved by his multimodal method of *transfers,* his application of a *general morphology,* and his ability to apply mental constructs and technology as seen in his compositional system, the so-called *UPIC (Unité Polyagogique Informatique CEMAMu).*

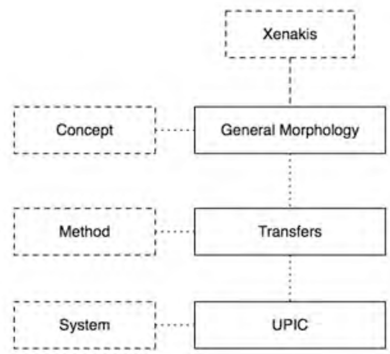


Figure 1: Diagram of Iannis Xenakis' developments

More recently, while contemporary science and technology have progressed through mathematical, computational, and informational processes, we have witnessed a similar progression of contemporary architectural methods which interface with these advancing technological concepts. These methods have been shown to be beneficial in the ability to fabricate complex geometries, develop parametric building systems, and to inform Building Information Models (BIM), assembled upon quantitative systems and processes within the architectural discipline. While these quantitative advancements have brought with them great achievement concerning efficiency and economic streamlining, these advancements have come at great qualitative cost to the social, public, and common good for which architecture is responsible. These consequences are most evident in the standardization of architectural form, the simplification of building program, and the disregard for contextual material applications evident throughout the majority of today's built structures (Novak M., 1992).

This is due, in part, to the loss of the shared relationships and valuable connections that architecture and music historically had with one another. These connections and relationships between architecture and music were paramount for providing the *fluency* of work to address how events and structures unfold through time, the *concepts* of instrumentation that forms identity and the *notational characteristics* that define the representational processes of each discipline. Marcos Novak articulates this situation in his essay, *The Music of Architecture*, stating "*Architecture is orchestrated of materials in rhythmic arrangements proportioned melodically" and, directing our attention to what he describes as "the timbre of space," explains: "Like a rich sound, a single such space has a wealth of overtones, partly inherent in the material itself, partly created by ornamentation, partly added by the passage of time and the accumulation of patina. By comparison, most of what we build today is very much like pure sine wave tones, correct but impoverished. Understanding the timbral dimension of architecture in cyberspace may help restore that richness to our barren real world environments."*

Novak continues stating, "*Composers, even if they have no formal architectural training, create spaces with a sophistication of concerns that architects often forget.*" (Novak M., 1992).

Contemporary examples of *archimusic* have continued to explore this interdisciplinary domain though the results have not yielded the same kind of impact and influence capable of moving the discipline of *archimusic* forward. These recent works can be seen implementing the associational and translational methods of the distant past rather than pushing the transformational methods forward. In fact, throughout the past few decades, there has been little advancement of these transformational methods, and it is here that we find ourselves today; in a field with a wealth of historical content that has more or less remained static for the last 30 years.

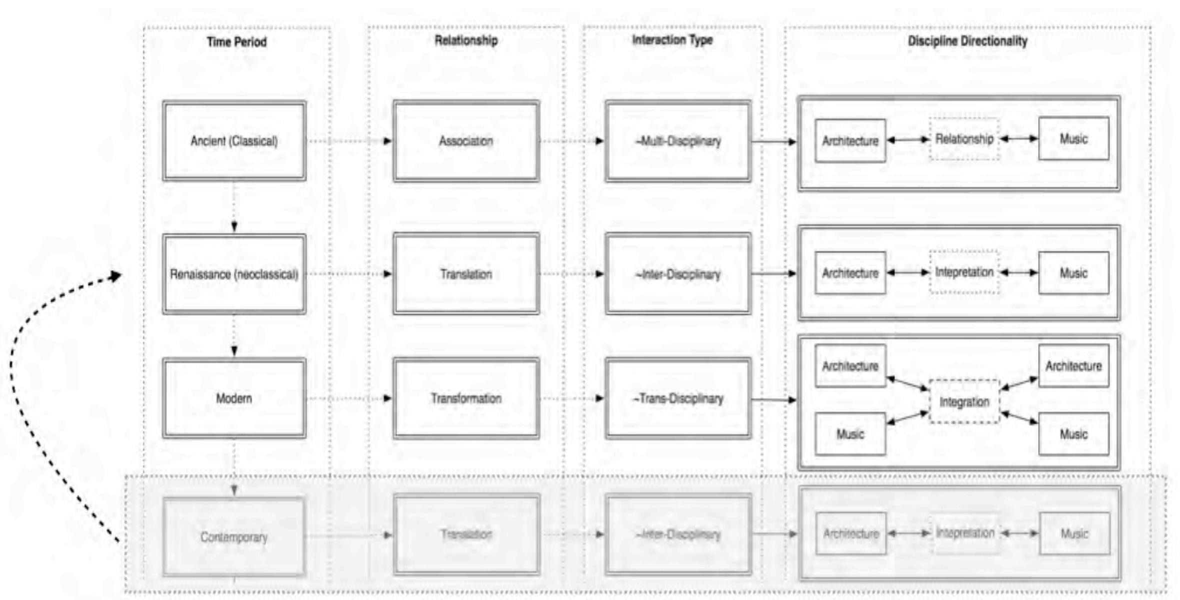


Figure 2: Historical integrations diagram

1.1 Problem Statement

The fundamental question at the core of this research is: *how can we advance the transformative and compositional methods of archimusic?* More particularly, this dissertation will contend with the following three problems, which together aim toward advancing the transformative and compositional methods of archimusic:

Problem 1: *How might the information and resources related to the intersection of architecture and music be organized into a learning resource that supports the future dissemination of this information?*

The lack of an organizational resource that frames the wide range of archimusical projects poses a significant gap in the field. There is a need for a resource that acts as a starting point for persons interested in the study of this trans-disciplinary field. Problem 1 will address the issue of how to collect and organize the resources for the continued study and research of the field of archimusic.

Problem 2: *What is a contemporary method for evaluating the trans-disciplinary relationships of archimusical works?*

Each archimusical work is a multimodal composition resulting from a trans-disciplinary process that informs certain elements within the work using an integrative or interpretative method. A contemporary evaluative study with the goal of understanding these multimodal processes, transformational integrations, and the trans-disciplinary nature of archimusical work has not been conducted. Problem 2 will address this issue of developing a method for evaluating and analyzing the trans-disciplinary modalities and translational processes that archimusical projects embody.

Problem 3: *How might a computational system be developed to generate new transmodal integrations between the digital forms of architecture and music?*

Despite ubiquitous computational advancements in both fields, a contemporary compositional system that promotes the generation of archimusical forms using contemporary computational methods does not exist. Problem 3 will address the generation of future archimusical works using a new generative system.

1.2 Significance

This research aims to expand the body of knowledge of *archimusic* by investigating the organizational, evaluative, and generative methods between architecture and music and integrating new technologies and techniques into the trans-disciplinary processes of archimusic. The goal of this research is to identify new territory and contemporary, computational applications for the future development of archimusic, seeking to pave new ground for how these two arts may continue to inspire each other and push the field forward. This research emphasizes the ancient connections and motivations that these two arts intimately share; advancing the field of archimusic and illustrating how these two arts may continue to inspire each other and promote more unity, beauty, and harmony within the visual and aural world.

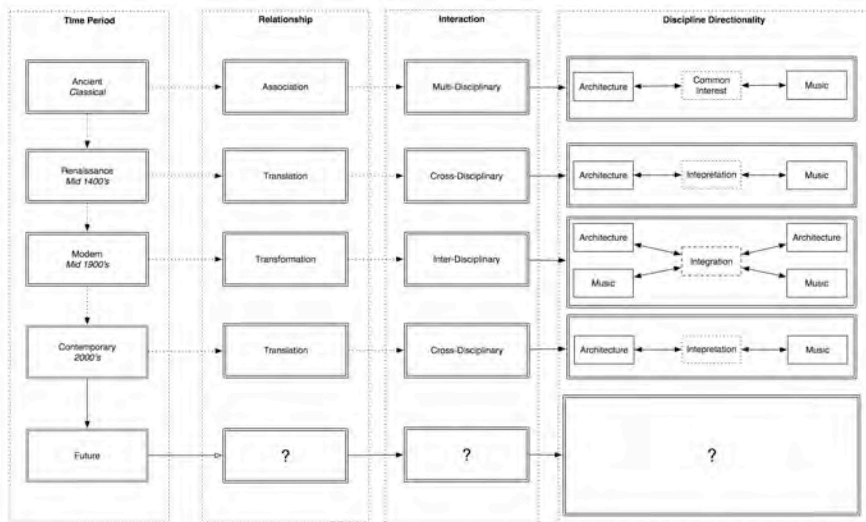


Figure 3: Future integrations diagram

1.3 Outline of the Dissertation

This dissertation begins with an introduction to the field of archimusic, including important terminology relevant to the research and particular projects that frame our perspective of the evolution of the field. Following this, an historical background of archimusic is described, and a survey of the trans-disciplinary relationships and integrations alongside projects and examples that exhibit these archimusical relationships is presented. Then Iannis Xenakis and his archimusical contributions to the field are introduced, outlining the role of "*computational composition*" (Novak M., 1989), sampling, and transformation as it relates to archimusic and its development. Next, the methodology is presented, and the three contributions that make up the main developments of this research are introduced. Following the methodology, these three contributions are described in detail. The first contribution is the *Archimusical Repository*, an online repository that addresses the need for a resource for those interested in and conducting research on the subject of archimusic. The second contribution is the *Archimusic Transmodal Matrix,* an evaluational taxonomic method to analyze the modal integrations of works at the intersection of architecture and music. The third contribution, *Kosmos: a system for Archimusic Synthesis*, is described last and provides a proof-of-concept generative-system that demonstrates how novel transformations can occur. This is accomplished by enabling a fluid workflow whereby the materials and processes of the digital modalities of architecture and music are abstracted and treated as liquid forms able to exist in all modalities at once. The next section presents a series of proof-of-concept studies that illustrate new archimusical generated works, directed toward different ends. These include several initial studies (which focus on simple translational approaches), the so-called "Sound Scans" (which focus on more intricate transformational approaches), and finally the "Allotope" (which focuses on the generation of a new archimusical work). Finally, before concluding, the possible directions for future work are addressed.

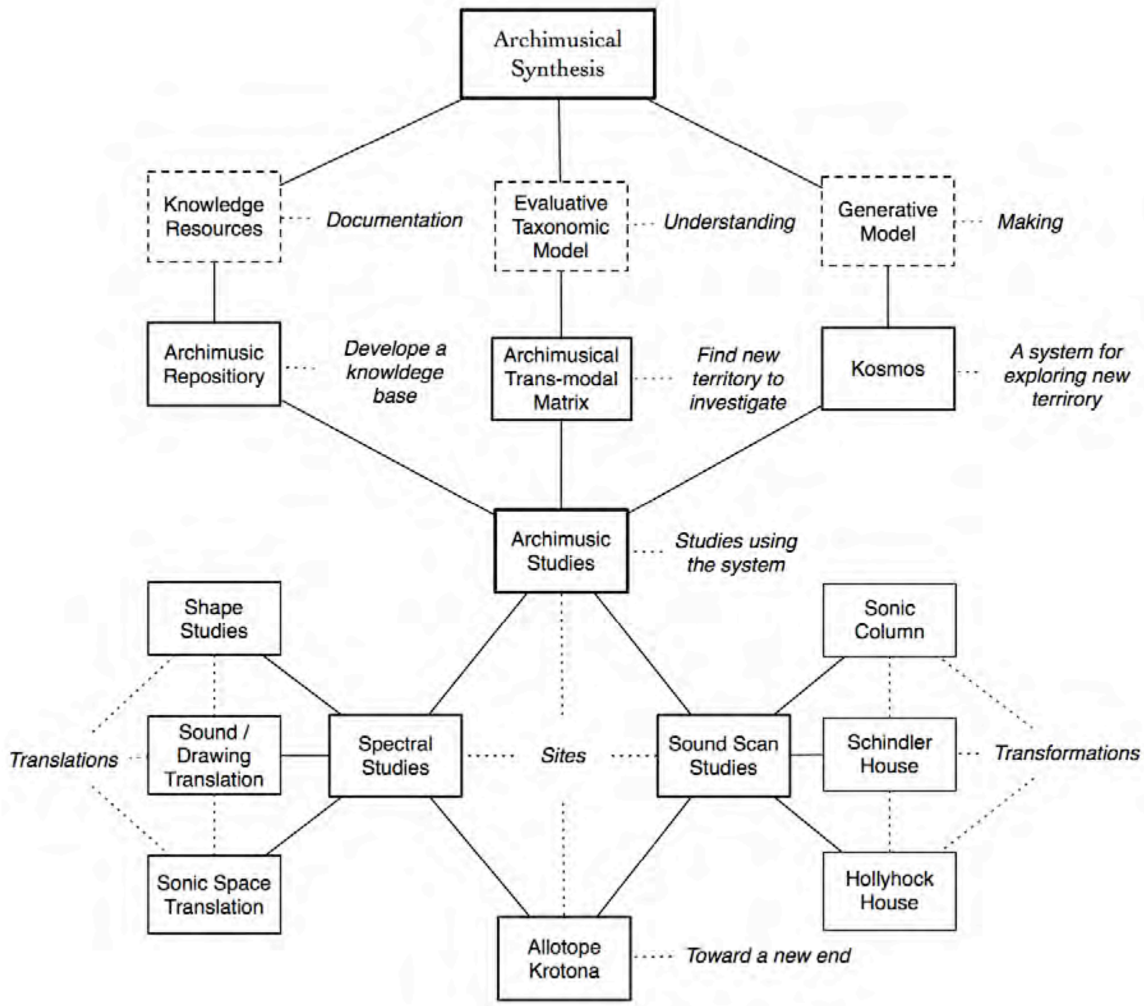


Figure 4: Structure of the dissertation research

2. Background

"Architecture is not a synchronic phenomenon but a successive one, made up of pictures adding themselves one to the other, following each other in time and space, like music."

~ Le Corbusier (Corbusier, The Modulor, 2004)

In the following paragraphs, we will introduce the topic of archimusic and present a brief but thorough survey of how archimusic evolved through four main historical periods. Examples of projects will be given that exhibit archimusical qualities during these periods. Finally, we will introduce the archimusical works and methods of Iannis Xenakis, which represent some of the most significant contributions to the field of archimusic.

2.1 Archimusic

Throughout time, architecture and music have found inspiration and direction in each other and their respective creative and technical processes; each seeking beauty, structure and unity in the ways that the other is composed, drawn, written, heard and built. As architecture can be understood as the purest of the spatial arts, so can music be referred to as the purest of the temporal arts (Bragdon, 2005) and together these two fields have developed intimate integrated relationships with one another. During times of heightened cultural advancement, architectural and musical works that have engaged one another have created some of humanity's most celebrated works. Works that intimately fuse these two disciplines are called Archimusic.

Archimusic is the integration of one or more digital or analog modalities from the disciplines of architecture and music towards a new end, such that the components of the final whole are non-separable. An Archimusical work uses, embeds, or integrates an element of one of its own compositional elements or processes with or within attributes or characteristics from the opposite discipline. For example, a work of music is informed by an architectural work, or, conversely, an architectural work is informed by a musical work.

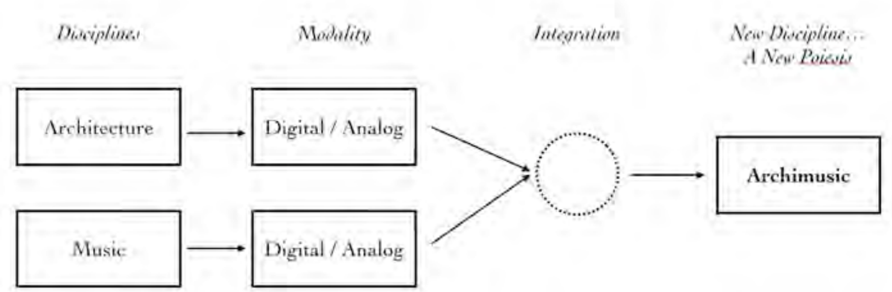


Figure 5: Archimusic discipline/modality integration

The term archimusic was coined by Marcos Novak in his essay *The Music of Architecture* (Novak M., 1992) and may be partially paraphrased as:

"this is a place where buildings can flow and music can be inhabited. When this is understood, the distinction between architecture and music can be set aside…therefore, I will refer to the combination of architecture and music with a new term, archimusic. As the name implies this is the art and science that results from the conflation of architecture and music.

Archimusic, in this research, is a field where architectural and musical thought and practice come together creating a field where architecture is musical, and music is architectural. The spatial and temporal qualities and quantities can be used to inform each other, making new types of hybrid compositions, toward new ends.

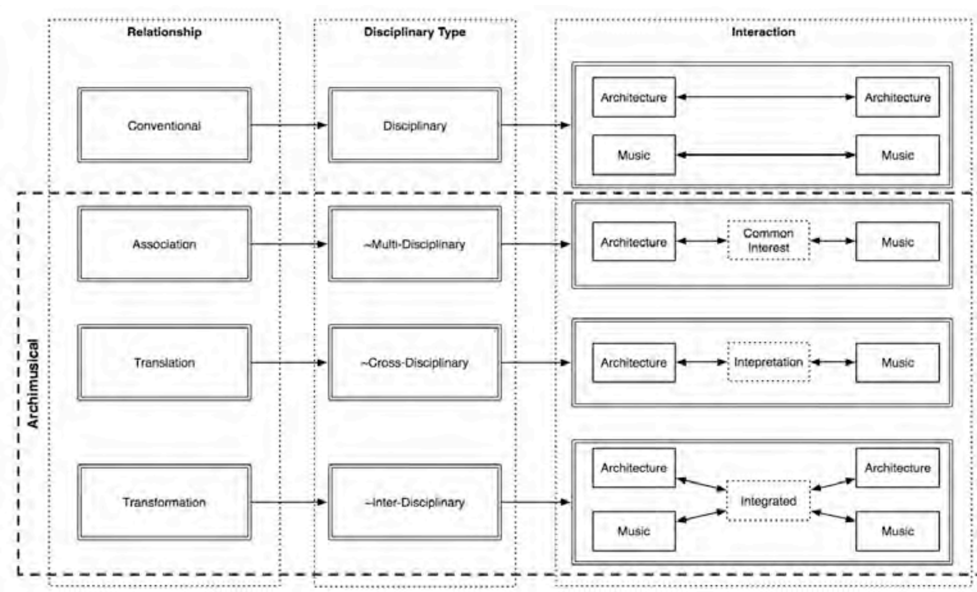


Figure 6: Diagram of archimusic relationships and interactions

Marcos Novak's concept of Archimusic has two aspects. The first aspect, *Archimusic within Information*; is concerned with the casting into information space of the architecture and music of the actual world that we are all familiar with. This can be seen in the current explorations of virtual reality, gaming environments, and common cinematic themes. The second aspect, *Archimusic of Information,* is concerned with how these relationships develop and are composed out of their own raw materials and immanent forces. As Novak states, "*If archimusic within information corresponds to the familiar architecture and music of the actual world, then the archimusic of information is the virtual analog to thunder, the sea roar, or birdsong. Archimusic is to visualization as knowledge is to information"* (Novak M., 1992). Visualization is "within" information as Archimusic is "of" knowledge.

These two ideas have extended the awareness of trans-disciplinary design between architecture and music. While the first is what we might consider commonplace in the current computational world, this research will be concerned primarily with the latter, the *Archimusic of Information*, and will continue to extend this concept into new and unexplored territory by developing new methods and models by which to understand, design, and make.

Though the modalities of architecture and music have changed and evolved through technological advancements and achievements of progressing times, the arts of architecture and music remain principle parts of the creative expression of most cultures (Jencks, 2013). Architecture and music give form to cultural achievement and can act as indicators of when societies attain heightened development and of which areas of that development are viewed as the most important (Garfias, 2004). In order to maintain a manageable scope, the historical overview of this dissertation focuses on the western perspective of the Ancient, Renaissance, Modern and Contemporary time periods. It would be an interesting future undertaking to consider how eastern, middle-eastern and other cultures have explored similar concepts, for they too have a rich and intersecting history of both architecture and music.

A distinction can be drawn between "archimusic," per se, and the "archimusical." Though the intent is to focus and frame archimusic towards a new end, such that the components are integrated and non-separable, it is important to include works that engage the relationships of both arts (*archimusical*) though they may not be complete integrations (*archimusic*), for these too are important steps towards the making of a new field. For this reason, we have included works that fall in this periphery of the field.

2.11 Terminology

A few definitions need to be given to understand the foundation of this research. These terms will often be used and describe important distinctions and fundamental aspects about projects, processes, and methods throughout this research.

- *Discipline*: A *discipline* is a branch of knowledge. In this research, the disciplines in question are *architecture* and *music*, as progenitors, and *archimusic*, emerging from their fusion.
- *Modality*: A *modality* is a particular mode or form in which something exists, is experienced, or is expressed. In this research, the modalities are the *actual* and the *representational.*
- *Domain*: A *domain* is a territory that exists within a given modality. In this research, the domains are the *physical* and the *virtual.*
- *Modal Element:* A *modal element* represents a particular domain of a particular modality of a particular discipline.

As we proceed through the research, the conversation will be concerning itself with different types of relationships, interpretations, and integrations. In general, these terms will be used to define three types of connections between the disciplines of architecture and music.

- *Relationship*: The manner in which two or more modalities are related.
- *Interpretation:* The process of converting one modality into another.
- *Integration*: The process of combining two or more modalities so that they become a new whole.

These relationships, interpretations, and integrations will be used to illustrate and explicate how the different modalities of architecture and music are connected. These modalities are the *actual* and the *representational* and are concerned with methods of *notation* and *instrumentation* respectively.

- *Instrumentation*: The design, provision for, or use of particular instruments, employed in a manner in which a piece is arranged.
- *Notation*: A series or system of written symbols used to represent numbers, amounts, or elements in something such as music or mathematics.

Different kinds of relationships and methods of integration will be discussed. These represent possible manners of connection between the architectural and musical modalities.

- *Conventional* relationships are based on or are in accordance with what is generally accepted by a culture or subculture.
- *Associational* (multidisciplinary) relationships are connections or cooperative links that unite two or more separate entities with one or more common purposes.
- *Translation* (cross-disciplinary) interpretations are formal or technical processes or conversions that enable the movement of something from one form or place to another. A translational interpretation is the conversion of one form or medium into another, or the communication of the meaning of a source-form or field, using an equivalent target language, into a destination-form or field.
- *Transformation* (trans-disciplinary) integrations (through shaping, trans~ or dia~) are relationships of change or alteration of form, shape, procedure or formational

process. Transformations are a thorough or dramatic change in one element or form into another that is equivalent in some important aspect but is expressed or represented in a different modality.

These integrations have a corresponding interaction type. These interactions depict the disciplinary relationship of the integration of relationship. Associational, translational and transformational relationships are to integrations as multi~, cross~, and trans~ operations are to interactions. As integration is to modality, interaction is to the discipline as noted in Figure 7.

- *Multi~*: Depicting more than one discipline or modality.
- *Cross~*: Linking *from* one discipline or modality to another.
- *Trans~*: Extending *through* one discipline or modality into another.

As a general heuristic these relationships, integrations, and interactions follow a certain connection pattern. Exceptions exist, and in some instances, the connection is multidirectional or even fed back on itself, but the following diagram (Figure: 7) generally holds true.

2.2 Historical Survey

The historical connection between architectural and musical works that incorporate one another is said to begin in the mid 15th century with Filippo Brunelleschi's *Duomo* in Florence and its relationship with Guillaume Dufay's musical composition *Nuper Rosarum Flores* (discussed in Section 2.22) (Warren, 1973). However, upon closer examination of the foundational principles of architecture and music, we can find examples dating back to the times of the ancient Greeks. These ancient relationships, which will be discussed next, may seem different from the ways in which the arts and sciences of architecture and music are related in modern or contemporary times, but these ancient connections are a testament to the inherent bond that these two disciplines share.

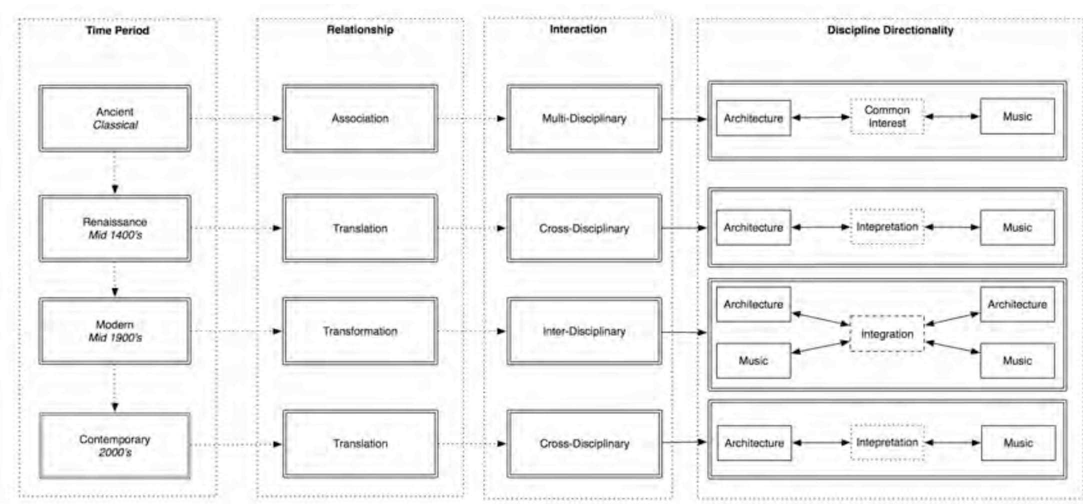


Figure 7: Diagram of historical relationships

2.21 Ancient**:** *Associational*

According to the conceptual scheme proposed by this dissertation, the ancient relationships between architecture and music were *associational* in nature, where architectural and musical works were each created by means of other modalities relating the mathematical, geometric, or cosmological world views that we recognize through the classically-inspired Medieval Trivium (grammar, rhetoric, logic) and Quadrivium (arithmetic, geometry, astronomy, and music). Commonly known examples of these are the musical intervals and harmonics of tonal music, and the spatial organization and arrangements of ancient temple sites throughout the Greek landscape and the proportions of symmetries of classical architecture that incorporate mathematical and geometric principles similar to those used in ancient and classical music. (Ferrera, 1996).

Pythagoras of Samos is said to have been one of the first thinkers to discover the connection between mathematical proportion and musical harmonics (Riedweg, 2005). The proportionalities of the tones of anvils and hammers ringing from a blacksmith's shop in the 6th century BCE (as legend has it) came to inform and explain the musical ratios known as *harmonics.* It was though that the regularity of these proportions could relate the strings of the lyre to the planetary orbits of the planets, and, thus, to the order of the cosmos as a whole. Pythagoras extended the concept of harmonics to the heavens, providing the basis for what came to be known as *Musica Universalis* or the *Music of the*

Spheres (James, 1995). Protagoras, another pre-Socratic Greek philosopher also theorized a cosmic relationship between music and proportion, reportedly stating:

> *"Man is the measure of all things: of the things that are, that they are, of the things that are not, that they are not"* (Bostock, 1988)*, and "There is geometry in the humming of the strings; there is music in the spacing of the spheres"* (Calter, 1998).

Harmony, from the Greek word *harmonia (αρμονία)* meaning, "fitting together, joining," is the essence of balance, unity, and compatibility between two or more parts or elements (Doczi, 1981). As Gyorgy Doczi discusses in his book, *The Power of Limits*, "Harmony is a *dinergic* relationship, in which different and often contrasting elements complement each other by joining." The proportional relationships inherent within musical harmonics are a foundational principle at the core of ancient spatial thinking as well.

From the cosmos to the string of the lyre, we turn to the arrangements of the ancient Greek temple sites.

The layout and organization of many ancient Greek temples exhibit similar ratios and proportions, as presented by Constantinos Doxiadis in his book *Architectural Space in Ancient Greece* (Doxiadis, 1972). Doxiadis' findings connect systems of coordinates, numerical spacing, and human perspectives to the location and orientation of twenty-nine ancient Greek and Roman temple sites. Using twelve and ten-part systems of polar angles, Doxiadis details the harmonic relationships within constructed elements, their spacing, size, viewing angles, and site construction. Intriguingly, Doxiadis demonstrates an observation from a centripetal perspective, which is also seen as a method for visualizing musical/electrical signals, mapping frequency, amplitude, and phase with a modern oscilloscope. This can be imagined as a spatiotemporal thought experiment of an ancient process applied to modern technology.

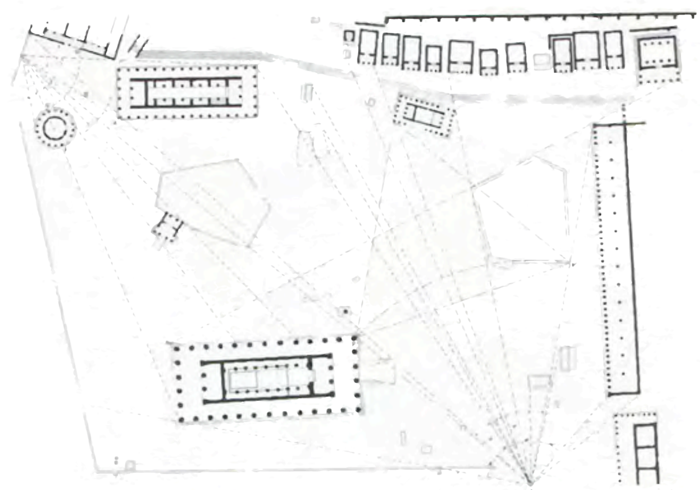


Figure 8: Sketch of Doxiadis' study of the Athens Acropolis. Image: (Doxiadis, 1972)

The notion of perspective and the proportions of the individual temples of these ancient sites conform to similar rules, such that what is true for the very big is also true for the very small. The facades and plans of these ancient monuments are designed with similar ratios; proportions and their relationships to harmonic proportions have also been widely studied and documented (SEGHERS, 1964) (Pollio, 1914).

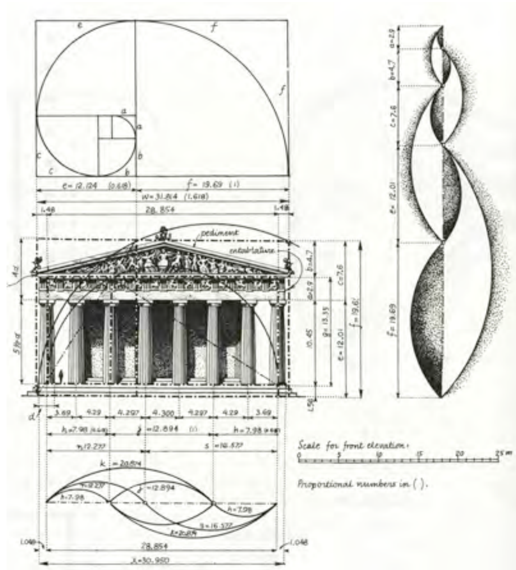


Figure 9: Doczi's drawing of proportional harmonies and the Parthenon. Image: (Doczi, 1981)

For the Greeks, these harmonic proportions connected time, space and material, creating a holistic approach from the microcosm to the macrocosm. The mathematic and geometric thinking of the ancients could relate the most abstract of terms and conditions by using the truest of languages, and, by doing so; the ancients wove the rational world together into its own harmonic relationship. It is important to note that these ancient ideas, though largely considered archaic and rooted in the distant past, hold some of the most promising potentials for future developments of archimusic. This research and the developments that will be introduced and described in later sections have been influenced greatly by the study of these ancient relationships.

2.22 Renaissance: *Translational*

Beautiful examples of the relationships between architecture and music continued to develop in the Renaissance, some 2000 years after the works of ancient Greece. Here we find an interesting advancement of the ancient relationship between architecture and music. As the prior examples have outlined, the ancient associational relationships between architecture and music, built upon the common ground of mathematics, geometry, and astronomy, began to evolve into translational interpretations in the works composed and constructed during the Renaissance. This was done by devices such as taking a piece of music or a work of architecture and translating it into the other by interpreting drawings as scores, or by employing the same harmonic ratios in music as in the proportions of a building. During this time two significant works stand out: the dome of the *Cattedrale di Santa Maria del Fiore* (known as *Il Duomo*) in Florence, designed by Filippo Brunelleschi, and the *Villa Rotunda* in Vicenza, by Andrea Palladio.

Perhaps the best-known example from the Renaissance is Brunelleschi's *Il Duomo*, at that time the largest dome in the world. The Florence cathedral had sat for over 100 years without a dome with no one able to solve the monumental feat of engineering a dome to span nearly 150 feet. In 1418, the church decided to hold a competition to search for someone to complete the task. Filippo Brunelleschi, a goldsmith, convinced the judges that he could accomplish the task and indeed, succeeded in doing so. To celebrate the accomplishment, the church commissioned Guillaume

Dufay to write a musical piece for the completion of the dome and overall cathedral and its consecration in 1436. Dufy composed the musical work based on Brunelleschi's drawings of the lantern's proportions atop the dome. This work is known as *Nuper Rosarum Flores* (Warren, 1973), and is a temporal reading of the dome's spatial proportions translated into a musical composition.

This account, though widely accepted, harbors some disagreement, as mentioned by Craig Wright in his essay, *Dufay's Nuper Rosarum Flores, King Solomon's Temple, and the Veneration of the Virgin* (Wright, 1994). Here Wright disagrees with Warren stating that the proportions are in fact biblical and based on Solomon's Temple (6:4:2:3) whereas the Il Duomo ratios are 3:2:1:1.5. In 2001, Martin Trachtenberg refuted Warrens claim and provided several different readings to the relationships of Dufay's *Motet* finally stating, "Wright is indeed correct in his thesis that the numerical structure of Dufay's *Motet* is referential" (Trachtenberg, 2001).

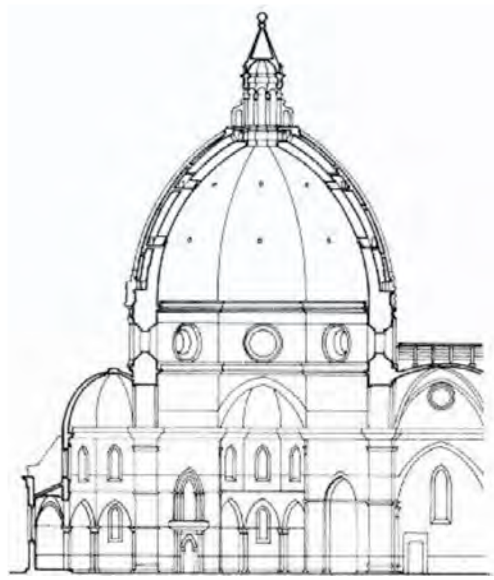


Figure 10: Il Duomo di Firenze by Brunelleschi (1436). Image: http://www.greatbuildings.com/buildings/Florence_Cathedral.html

The *Villa Rotonda* (also known as *Villa Capra*) was designed by the Italian architect *Andrea Palladio*, and long held as one of the most beautiful pieces of Italian Renaissance architecture. The facade and plan of the Villa have been based on proportions similar to those of ancient Greek temples. These principles employed include basing the villa's arrangements on the Golden Section and ratio (1:1.618), thought to be sacred for its common trait being found throughout natural and organic processes (Rowe, 1982) (Wittkower, 1971). The *Pantheon* in Rome rebuilt by the Roman emperor Hadrian and designed by Apollodorus of Damascus is also thought to have served as an inspiration to Palladio, along with Hadrian's Villa, which was well known to Palladio and referred to throughout his writings (Palladio, 1965).

It is important to note that this position is augured against in the paper, *Harmonic Proportions and Palladio Quattro Libri* (Howard, 1982), and indeed Wittkower does point out the problem with harmonic proportions and the Villa by dedicating nearly a whole chapter to it in *The Architectural Principles in the Age of Humanism*. But, whether or not the facade design of the Villa Rotonda was intentionally based on the golden section, as Wittkower notes, or on other numerical and harmonic systems, the central focus of the work is the revival and use of the methods of the ancients, as he understood them. Wittkower states, "proportions in architecture have to embrace and express the cosmic order" and continuing, "revealed by Pythagoras and Plato, whose ideas in this field had always remained alive, but gained new prominence from the late fifteenth century onwards." (Wittkower, 1971).

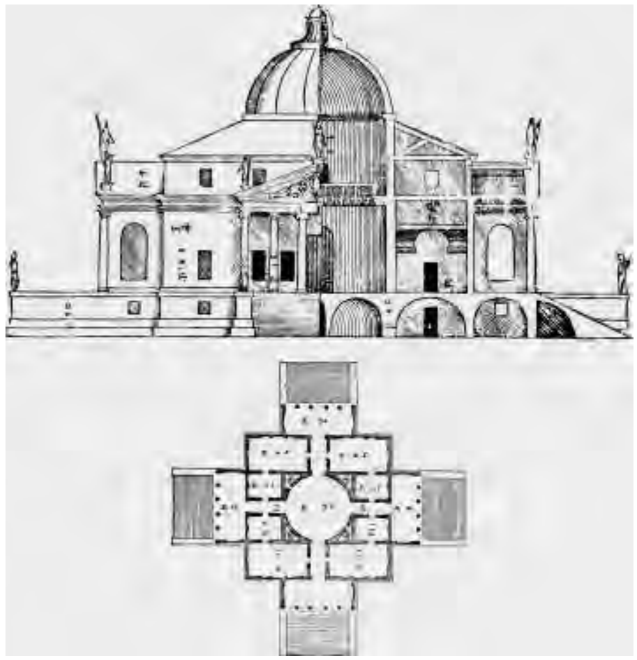


Figure 11: Il Villa Rotunda drawing by Andrea Palladio (1567). Image: (Palladio, 1965)

As we have expressed in the past two sections, architecture and music share an inspiring history, dating as far back as ancient Greece. How have architecture and music been related to one another in more recent times?

In the following sections, we engage more recent advancements between the disciplines of architecture and music. We consider projects from the mid-20th century and the present, examining the significant contributions they made to their respective periods.

2.23 Modern: Transformational

During the modern period, especially after the mid-20th century, the previously mentioned translational methods of the Renaissance evolved into transformational integrations by using compositional methods and practices found in one modality and incorporating them into the other. During this time, the Western world would see the development of electronic music. By the 1950's, magnetic tape, loudspeakers, and other electronic media became adopted by musicians as tools of composition and synthesis, affecting the understanding of Music as a whole. Architecture, on the other hand, did not see the design tools advance in a similar, compositional way. Modernization focused primarily on pragmatic improvements to fabrication processes, material standardization, economies of scale and industrialization, and efficiencies in the production of architectural documents, but most architects did not initially seek the deep experimentation that composers undertook. An engineer, architect, and composer Iannis Xenakis saw this potential and began to experiment and develop projects that have since paved the way for new forms of architectural and musical integration.

We will discuss the works and process of Iannis Xenakis thoroughly in section 2.5, but for this section, it is important to introduce few of his projects that began to fuse the practices of architecture and music in transformational ways. These projects would be some of the first examples of immersive installations and electronic or media art. The *Philips Pavilion* (1958), and the audio/visual spectacles known as the *Polytopes* (1967-

1978), and the *Diatope* (1978), represent some of the most prominent examples of this transformational integration and form, in the opinion of this research, the foundational canon of what came to be known as *archimusic.*

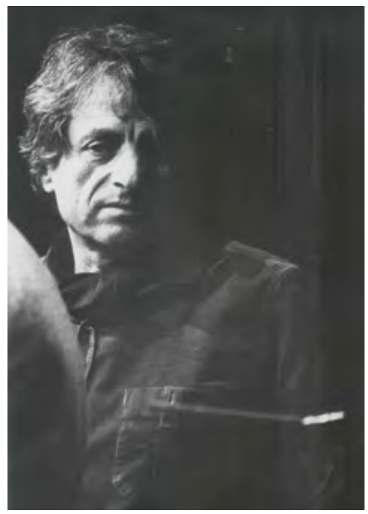


Figure 12: Iannis Xenakis. Image: http://iannis-xenakis.org

While working for the famous modernist architect Le Corbusier, Xenakis (initially trained as an engineer, but studying to become as composer) was in charge of engineering tasks and design process. For the Convent Sainte Marie de La Tourette near Lyon, France, Xenakis was required to design an engaging glass facade, sized particularly for material standardization.

As an emerging composer, Xenakis approached designing the facade with rhythm in mind and converted what might have been a conventional, repetitive, and monotonous facade into a musical/spatial *pan de verre ondulatoire* or undulating glass panels (Xenakis I. a., 1976). Casting a visual rhythmic composition of shadows and light from the glass and mullions, this facade was a musical score translated into architectonic space.

Figure 13: Convent la Tourette by Le Corbusier & Xenakis.

Image: fondationlecorbusier.fr

Another example, and perhaps the best instance in the history of the relationship between architecture and music, is the *Philips Pavilion* (*Poème électronique*) built at the *1958 World's Fair* in Brussels. The Dutch Philips Company commissioned Le Corbusier to design the pavilion to showcase the technological innovation of the company. The design of the pavilion was influenced by Xenakis' musical composition *Metastaseis* (1954) and Xenakis, who was given shared credit for the creation, was in charge of the design. Using his knowledge of engineering, architecture, and music, fusing them into what is regarded as one of the most influential pieces of musically-inspired architecture of the time (and of *archimusic*, according to this dissertation). The initial design of the pavilion was an architectonic transformation of the glissandi found in bars 309-314 (Xenakis I., Music and architecture: architectural projects, texts, and realizations, 2008) of his musical composition *Metastaseis*.

To accompany the musically-inspired architectural composition, Xenakis also composed the spatially conceived *Concrete PH* (1958), to be played as the visitors entered and exited the pavilion, bookending the main musical composition, *Poème électronique*, written by Edgard Varese.

The inside of the space was a sound and light show using film, still photo, and colored light projection of a Le Corbusier montage depicting the arc of human civilization. Edgard Varese's piece was spatialized by an estimated 400 loudspeakers (estimates range from 350 to 450 speakers) that were dispersed scholastically across the inside of the hyperbolic-parabolic structure that was designed by Xenakis. More information about the Philips Pavilion can be found in *Space Calculated in Seconds* (1996), by Marc Treib, the book devoted to building. Treib concentrates primarily on the role of Le Corbusier and Edgard Varese.

Figure 14: Philips Pavilion - Le Corbusier and Iannis Xenakis (1958).

Image: fondationlecorbusier.fr

The Polytopes, from the Greek terms “poly” meaning “many” and “topos” meaning “place,” was a series of audio, video, and spatial “spectacles” using sound, light, color, and architecture in a live performance. The polytopes included the *Polytope de Montreal* (1967), *Polytope Persepolis* (1971), *Polytope de Cluny* (1972-74), *Polytope Mycenae* (1978). The Polytopes may be considered a summation of Xenakis interests and skills. His formation and experiences made Xenakis a prolific composer in both the realms of music and architecture. The last project we will mention here, though we will mention others in Section 2.5 is the *Diatope* located in Paris. Xenakis designed the vinyl pavilion and used flashbulbs and lasers guided by adjustable mirrors to develop an immersive architectural environment outside the newly inaugurated Centre de Pompidou in 1978.

Xenakis also designed the UPIC (*Unité Polyagogique Informatique CEMAMu* (CCMIX)) in 1977, one of the earliest computational composition tools designed to translate hand drawings into sounds (Xenakis I., 2008). The UPIC integrates a computational system into the translational and transformational methods, used to compose *La Legende d'Eer* (the musical composition of the *Diatope*) and *Mycenae Alpha* (the musical selection of the *Polytope Mycenae*).

Figure 15: Composition of Mycenae Alpha for the UPIC (1978).

Image: Iannis Xenakis Archives, Bibliothèque Nationale de France

Since the UPIC, computational models have become commonplace in both the fields of architecture and music. The computational methods of parametric and BIM (Building Information Modeling) have advanced the design and development process of digital architecture and have contributed to addressing quantitative questions of economy, structural integrity and workflow (Azhar, 2011). Computational synthesis methods and physical modeling have also become a common practice in the field of electronic and computer music, creating novel sound-forms able to be designed at the micro-scale. More recently, contemporary works that involve this trans-disciplinary interest have continued to be developed. However, these contemporary examples have regressed, becoming translational-based, all but abandoning transformational methods initially set out by Xenakis.

2.24 Contemporary: Translational Seeking Transformational

In contemporary times (late 20th century to early 21st century), the transformational approaches evident in the modern period and the work of Iannis Xenakis are nearly forgotten and instead utilize mostly the same translational methods seen during the Renaissance. The majority of examples that we will look at in this section will be pulling again from these translational methods in the work of Steven Holl, Wolf Prix of Coop Himmelblau, and Daniel Libeskind.

The Stretto House by Steven Holl in Dallas, Texas was inspired by *Music for Strings, Percussion and Celeste,* written in 1936 by Bela Bartok. The musical work is composed of four movements, and Holl's house mirrors this using rectilinear brick walls to divide the architectonic work and to connect it with flowing metal roofs that carry the voice of the strings (Holl, 1996). Bartok's composition collapses down and ends with the original tonality (Solomon, 1973), while the final room of the Stretto House uses all the materials and proportions scaled down to reflect a similar character.

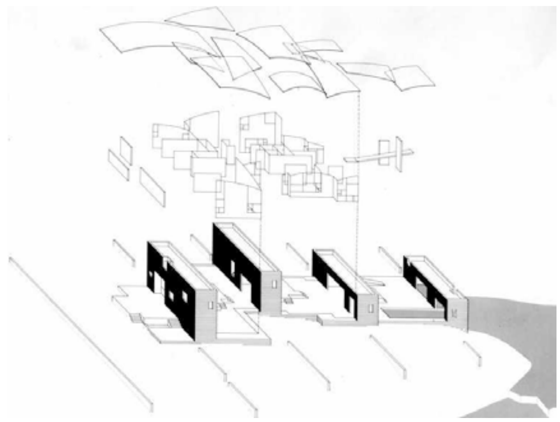


Figure 16: Steven Holl's Stretto House (1991). Image: http://www.stevenholl.com/projects/stretto-house

The Pavilion 21 MINI Opera Space by Coop Himmelblau is perhaps one of the best examples of contemporary archimusical translation using computational means that are in the direction of this research. "As a starting point towards the abstraction of music into a spatial form, a sequence from the song "Purple Haze" by Jimi Hendrix and a passage from "Don Giovanni" by Mozart were transcribed. Using frequency analysis of these musical works combined with the computer-generated 3D model, the musical sequences are translated into pyramidal "spike constructions" using parametric "scripting"" (Prix, n.d.).

Wolf Prix continues in an interview published in Dezeen stating: "The new digital design methods are highly appropriate to implement in a practical way the idea of surface enlargement designed as pyramid-shaped aluminum structures. Those have been generated parametrically through the overlay of sound frequencies from Jimi Hendrix's song *Purple Haze* and Mozart's opera *Don Giovanni*. These shapes act either as sound reflectors or as sound reducers" (Hynes, 2009).

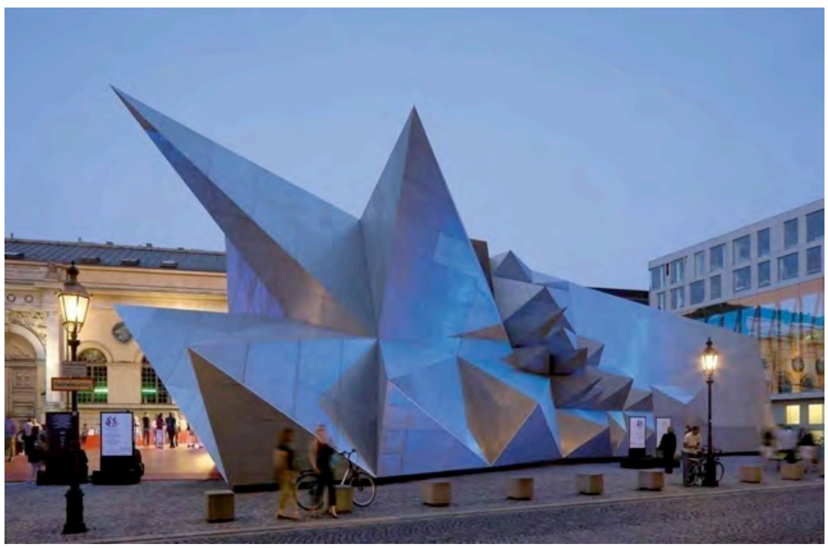


Figure 17: Coop Himmelblau's Pavilion 21 MINI Opera Space (2008-10). Image: Copyright Duccio Malagamba

In conclusion, the associational relationships found in the ancient examples advanced to become translational interpretations throughout the Renaissance. These translational methods again evolved into transformational integrations during the modern period, while the more recent contemporary examples of archimusic have primarily relied on newer forms of translational methods, though some transformational examples do exist. As the digital revolution of the 21st century becomes more pervasive and the information age associated with computers and computation continue their trend toward ubiquity, we find ourselves in fertile ground primed for the next advancement of archimusic. In the continued evolution of archimusic, we seek to develop these transformational methods in order to advance this trans-disciplinary field.

2.3 Relationships and Integrations

Architecture and music can be integrated using different methods. There are parallels between both fields that are surprisingly similar to one another in both the abstract conception of each art form and in their methods of composition. We can relate aspects of architecture and music in a number of meaningful ways, including soundscapes, aural architectures, cymatics, architectural acoustics, spatial sound, sonic spaces, instrumentation, and notation. The latter three, *notation*, *instrumentation* and *sonic spaces* will be the primary focus of this section and can be used to compose and construct spatial sound and sonic spaces. The subject of notation is interested in the ways that design and compositional processes relate to their representative forms, while instrumentation is concerned with how these representational forms are implemented into material or structural forms.

Depending greatly on site, context, culture, material, scale and organization, these methods play a crucial role in the processing, interpreting, and understanding of design decisions with regard to the sonic signature and characteristics of a space. With such understandings, our spaces can be more favorable to experience and can offer greater benefit during the time that we spend in them. They call to our senses and can harmonize with the visual phenomena as well as provide valuable feedback as to how the visual might be designed. Designing and composing with these methods, create an increased awareness and understanding from one discipline to another and is a significant interest in this research and related studies.

In the following section, we present the relationships of *notation*, *instrumentation*, *spatial sound,* and *sonic spaces*. Lastly, we and briefly outline some additional types of integrations related to, but not a focus of, this research.

2.31 Notation

The systems of musical scoring and the methods of drawing found in architecture have overlapping areas of interest within their respective notational systems. Notational relationships are concerned with how the design and compositional process relates to its representative forms; a drawing is representational of the actual building just as a score represents the actual music. The actual and representative modalities of architecture and music contain both a spatial and temporal component and each is designed or composed in the mental sphere and performed, executed, or built in the physical sphere. Architects and musicians have continued to find this commonality inspirational when composing music or designing architecture.

In this section, we take a deeper look at notational relationships, especially graphic notation. We then introduce the following interrelationships between architectural drawings and musical scores citing specific examples from the texts of Jim Lutz, Alessandra Capanna, and others

2.311 Signs and Symbols

Scoring and drawing are the written form of music and architecture; they are the diagrammatic compositions of signs and symbols that visually represent all intended expression. Representing how the material will be used and what it will express in the case of architecture, or which instrument will play what tone with what character in the case of music.

Conventional forms of notation follow a traditional or classical methodology, symbolizing certain instrumentation to be performed in a manner conforming to historical styles, and offering predictable developments. In an effort to create less conventional and more abstract forms of sound and space, signs and symbols can have entirely different representations or be entirely absent and replaced with some other mark, perhaps inspired by a wholly different discipline. When these abstract methods are used in the notational exploration of music and architecture, the results can be stunning, inspired, and expressive, with nearly endless interpretations.

Professor and former Dean of Princeton University's School of Architecture Stan Allen defines diagrams as "explanatory devices to communicate or clarify form, structure, or program… a graphic assemblage that specifies relationships between activity and form, organizing the structure and distribution of functions.” (Allen, 1998). These graphic assemblages specify relationships that can and do create a visual language similar in both disciplines of archimusic. This notational modality encourages cross-disciplinary collaboration between architects and composers. This connection facilitates the transfer of domain specific information outside of its conventional threshold, informing one another and becoming trans-disciplinary. As the score becomes spatial and the drawing becomes musical, these graphic notations create new forms of expression and interpretation, the notations of Goethe's *frozen music*.

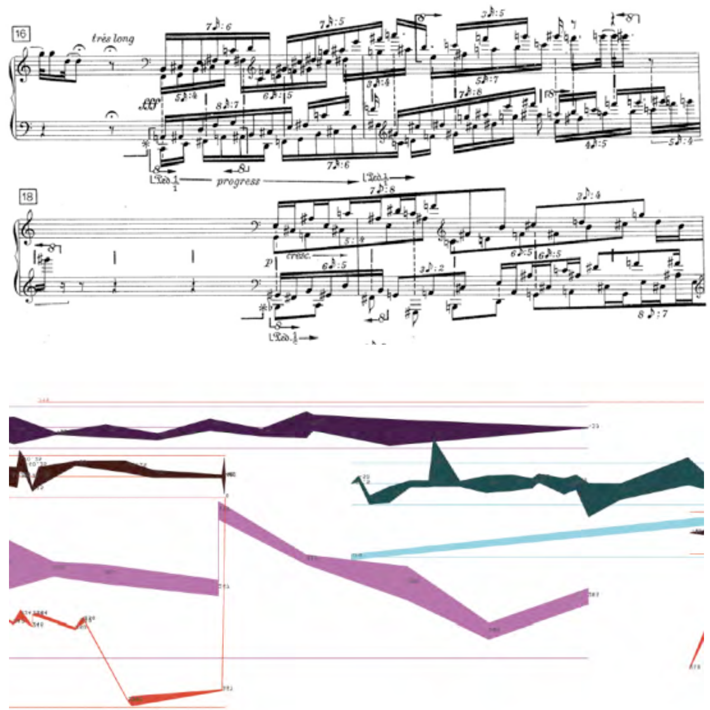


Figure 18: Notation: Op 72 by Chopin (Traditional) & Solitude by Steiner (Graphic). Images: C.F. Peters Corporation & Hans-Christoph Steiner

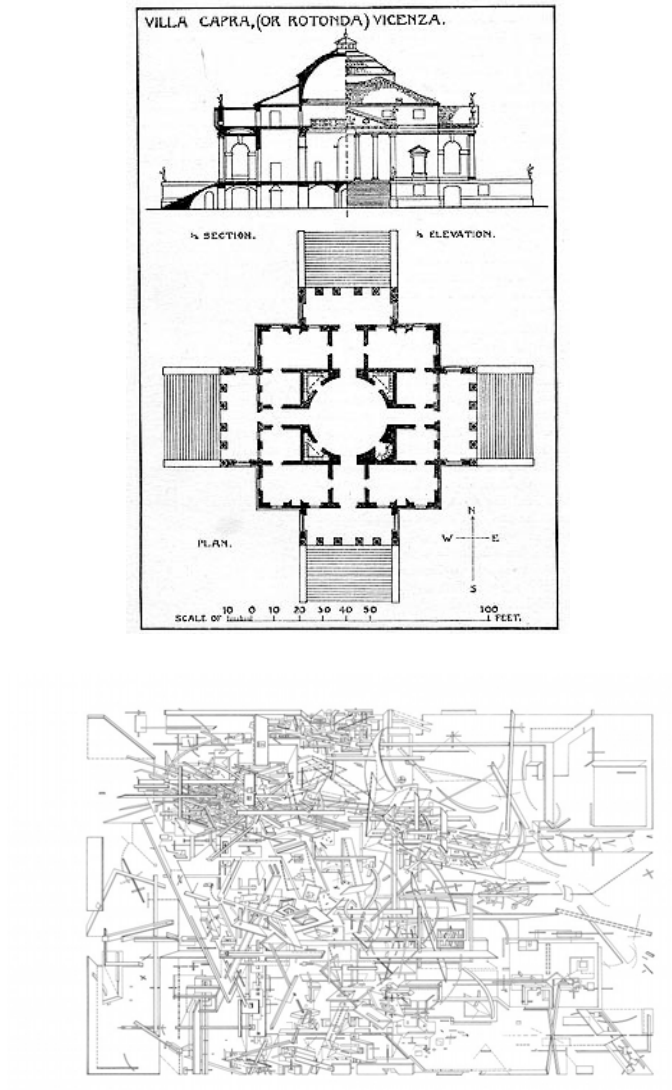
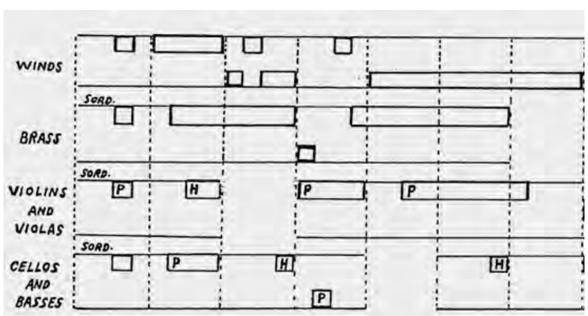


Figure 19: Drawings: Palladio's Rotunda (Traditional) & Daniel Libeskind's Micromegas: Little Universe (1979) (Graphic). Images: (Palladio, 1965) & http://libeskind.com/work/micromegas/

2.312 Graphic Notation in Music

Graphic Notation is “the representation of music “by which visual shapes or patterns are used instead of, or together with, conventional musical notation” (Latham, 2002). The use of visual symbols outside the realm of traditional music notation is conventionally known in the field of music as “graphic notation” and has been practiced since the 1950's. Composers such as Feldman, Cage, Xenakis, and Stockhausen experimented with different methods of composing music through the method of drawing. Morton Feldman’s score for *Projections* represents one of the earliest examples of graphic notation in music. Inspired by the discipline of abstract art and spatialized sound the Projections series paved the way for a visual method to compose music.



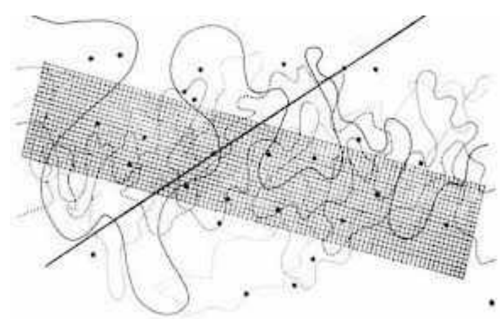


Figure 20: Projections 2 by Morton Feldman (1950-51). Image: Copyright 2017 by Edition Peters. Used by permission.

Fontana Mix by John Cage (1958). Image: Copyright 2017 by Henmar Press, Inc. Used by permission of C.F. Peters Corp

Inspired by Feldman's graphic series, John Cage also experimented with graphic notation and would go on to create scores such as *Fontana Mix* (1958) and *Variations 1* (1958). In 1968 John Cage published a collection of graphic manuscripts called *Notations* that illustrated the "many directions in which musical notation was now going," (Cage, 1970) and the book itself was composed using chance operations based on the *I-Ching*.

The graphic score of *Pithoprakta* by Iannis Xenakis premiered in 1956 by the German conductor Hermann Scherchen is another example of graphic notation in music. Scherchen, along with Olivier Messiaen championed Xenakis' work and encouraged Xenakis to pull from his architectural background and Greek heritage. *Pithoprakta*, whose name translates to "actions through probability" (Taruskin, 2009) is written for 50 instruments and is based on mathematical probabilities and statistics of Brownian motion and Gauss' law, where each instrument is a player in an equation that unfolds over time.

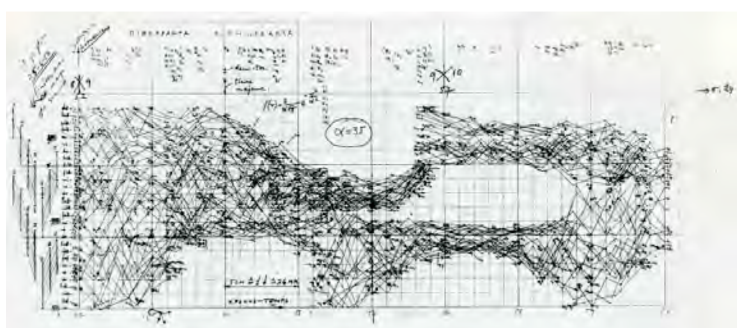


Figure 21: Pithoprakta Graphic Score by Xenakis (1956). Image: (Xenakis I., Musica, architettura, 2003)

Karlheinz Stockhausen also used graphics scores in his compositional process. Among them are *Kontakte* (1960), *Mikrophonie 1* (1964), and *Elektronische Studien II* (1974). He used his method to explore music and sound's relationship to space, creating spatial compositions such as *Musik fur ein Haus* and the pavilion for the 1970 World's Fair with Fritz Bornemann.

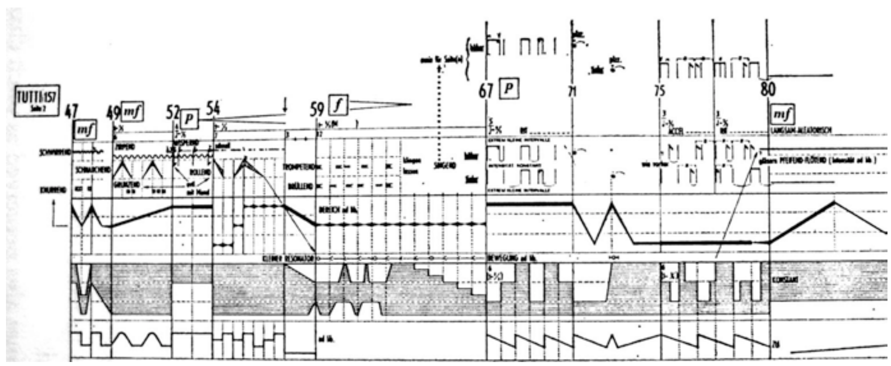


Figure 22: Mikrophonie 1 Tutti 157 Score by Karlheinz Stockhausen (1964).

Image: Universal Edition

Since the mid 20th century, many composers have continued to experiment with graphic notation up to the modern day. Artists such as Brain Eno, Will Redman, Pat Muchmore, and Hans-Christoph Steiner have made significant contributions to the visual form of graphic notation, each providing new musical interpretations and simultaneously informing the compositional act of drawing with musical concepts.

2.313 Graphic Notation in Architecture

In architecture, graphic notation is also present, though here we see the resulting artifact translated into a static form. Concerned with how spatial and temporal relationships of graphic notation and musical scoring are applied to the architectural design process it can be used to diagram a building's program, circulation, and spatial hierarchy as well as more abstract concepts such as those seen in the architect Daniel Libeskind's work.

The Chamber Works project by Libeskind is one such example. These 28 drawings are, as Libeskind calls them, "Architectural Meditations on Themes from Heraclitus" which are based on the philosophical writings of the pre-Socratic, Ionian philosopher Heraclitus. Jeffery Kipnis, in the collection of book of works called *Perfect Acts of Architecture* (Kipnis, 2001) calls the Chamber Works "the Apollo to the Micromega's (also by Libeskind) Dionysus" and discusses how the 28 drawings "form a score, one that must be played, however, for it cannot be read". Iannis Xenakis quoted an ancient phase by Heraclitus, which addressed a similar concept saying, "No man ever steps in the same river twice, for it's not the same river and he is not the same man" (Xenakis I., 1992). Though the relevance of this isn't immediately obvious, the meaning addresses the world's constant change of flux and its impact on Xenakis' musical and architectural compositions.

Figure 23: Chamber Works: I-V, III-V by Daniel Libeskind (1983). Image: http://libeskind.com/work/chamber-works/

The *Bebop Spaces* by architect and professor Bennett Robert Neiman illustrates a similar approach to Libeskind's *Chamber Works*. These drawings pull from the musical works of the influential jazz work *Leap Frog* by Charlie Parker and Dizzy Gillespie. The space, line, volume, and texture of the music are translated into complex geometries in three-dimensional space. In Neiman's Paper, he quotes Dizzy Gillespie "First you learn your instrument. Then you learn music. Then you forget both of those and just blow" (Neiman, 2006). This sense of flow is important component in the making of spatial forms using improvisational character of jazz. Having a fluent relationship with the instrument and space allows for a creative flow that is essential in the making of spatiotemporal archimusical forms.

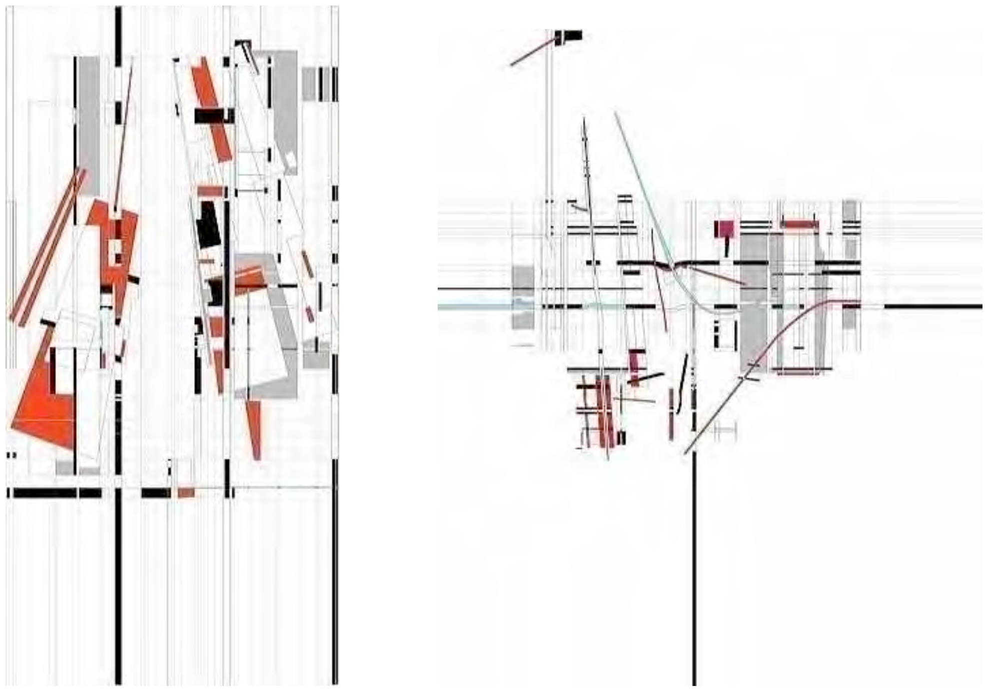


Figure 24: Bebop Spaces by Bennett Robert Neiman (2006). Image: (Neiman, 2006)

The *Manhattan Transcripts* by Bernard Tschumi is another project that exemplifies the relationship of graphic notation pushing beyond the predictable realm. Here Tschumi presents four episodes (Park, Street, Tower, Block). Using photographs, diagrams, and maps, Tschumi exhibits an architectural notation that pushes the boundary of convention and illustrates movement and events not typically represented in architectural drawings, pairing space and the action of an event (Kipnis, 2001).

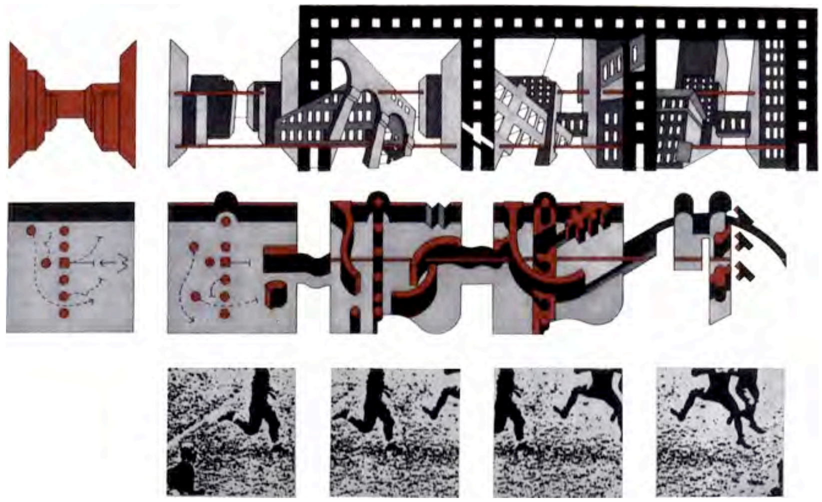


Figure 25: The Black from The Manhattan Transcripts by Bernard Tschumi (1976-1981). Image: http://www.tschumi.com/projects/18/

2.314 Architectural Drawings and Musical Scores

Jim Lutz has written on the interrelationships of both notation and instrumentation. In his essay *Along Parallel Lines: Architectural and Musical Notation,* Lutz defines two ways of understanding this concept. "*Architectural Drawing as Musical Scores*" is concerned with the properties of an architectural drawing and translating them into the representational domain of music, while "*Musical Scores as Architectural Drawings*" reverses this process, interpreting properties of a musical score into the representational domain of architecture. Alessandra Capanna in her essay *Music and Architecture: A cross between Inspiration and Method*, analyses bridging themes of architecture and music and the forms of composition that she terms "*pictorial, poetic,* *musical*" (Capanna, 2009). Below we examine the projects mentioned by both Lutz and Capanna, along with a few others, to illustrate works that have contended with graphic notation using different archimusical methods.

2.315 Architectural Drawings as Musical Scores

Lutz's notational category of *Architectural Drawing as Musical Scores* is concerned with properties or characteristics found within an architectural drawing or representative system and translating them into the musical domain. *Architectural Drawings as Musical Scores* can be considered a drawing meant to be a piece of architecture or an architectonic thought (Novak M., 1992), that is translated or transformed into the modality of a musical score meant to result in a musical work. In the following paragraphs, we review projects described by Lutz that accomplish this in various ways.

The *Waterloo Terminal* score (1998) is a work by Tetsu Inoue that converts images of the Waterloo Terminal by Grimshaw Architects into a musical work. The work was created by using one thousand different images relating to the architecture of the terminal and scanning them into sound using the program *MetaSynth*, a graphical sampling tool that sonifies images by treating them as spectrums. The images used were architectural drawings including sections, plans, and details as well as pictures taken of the interior and exterior of the terminal (Lutz, 2014). Inoue then used these sounds to compose the musical pieces.

The Pasadena, California based artist Steve Roden was asked to create a work for the 2005 Serpentine Gallery Pavilion designed and built by Siva Architects and Cecil Balmond. The Pavilion utilized a wooden column-less *lamella* structure that creates deep coffers in a 3-dimensional gridded formation. Steve Roden's process was two-fold. First, he used the colors associated with the notes of a *glockenspiel* and assigned the colors to the coffers of the lamella structure using chance operations. The architectural plan and elevation drawings became colorful scores that could now be played. Roden also attached contact microphones to the structure and used the sounds in the composition by sampling the material structure (Lutz, 2014). This component of the project marks an interesting segue from the *Architectural Drawing as Musical Scores* and into the realm of instrumentation.

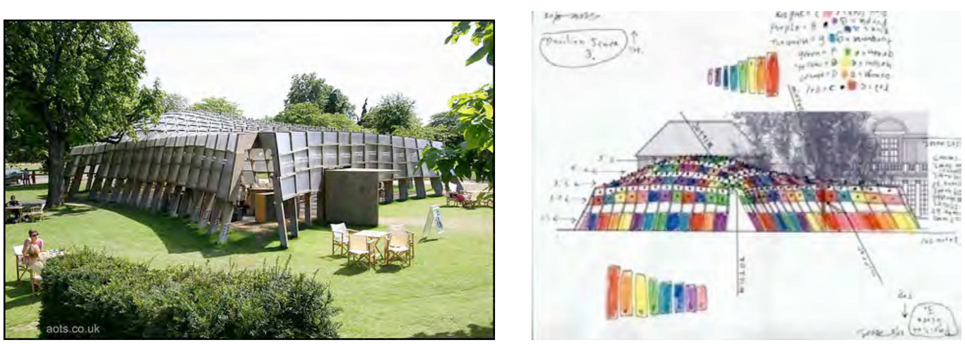


Figure 26: 2005 Serpentine Pavilion by Álvaro Siza and Eduardo Souto de Moura

Image: *Sylvain Deleu* and score drawings by Steve Roden. Image: Steve Roden

http://www.inbetweennoise.com/works/sounding-architecture-and-pavilion-scores/

As discussed in the historical overview, Guillaume Dufay's composition *Nuper Rosarum Flores* was also inspired by architecture. The composition was based partly on translating the physical proportions of the Santa Maria del Flores cathedral cupola into the interval and temporal structures of the musical piece.

The *BMW Welt* by Coop-Himmelblau (2006) used an interesting approach to this category by taking the gestural geometry from the building and using it as a score. The digital geometry was sonified with the X-axis representing time and the Y-axis representing frequency. The details of this experimentation were briefly mentioned at a Wolf Prix lecture at *SCI-Arc* in 2011 (Prix, *What's the Difference Number One.,* 2011).

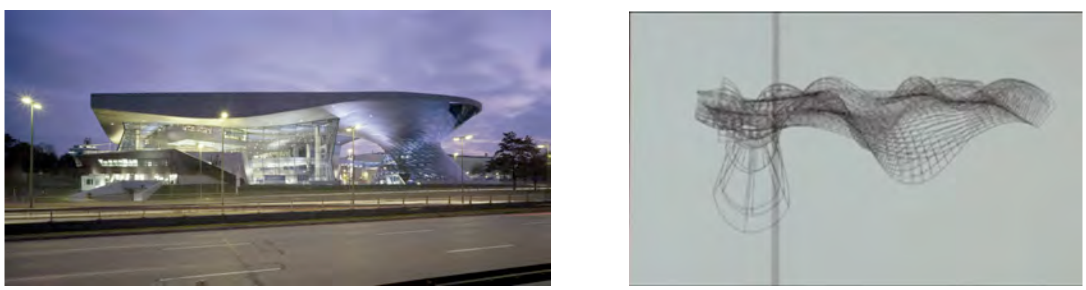


Figure: BMW Welt by Coop-Himmelblau and sonification slide by Coop-Himmelblau. Image: © 2007 Ari Marcopoulos & © Coop-Himmelb(l)au

2.316 Musical Scores as Architectural Drawings

The other notational category described by Lutz is *Musical Scores as Architectural Drawings*. This category reverses the previously described process by interpreting properties of a musical score into the representational architectural domain of spatial plans and drawings. A score meant to be performed, or meant to be a musical thought is translated into the modality of architectural drawing. In the following paragraphs, we review a few projects described by Lutz and others that use different methods to accomplish this.

The *Stretto House* in Dallas Texas (1991) by the New York based architect Steven Holl (Figure 16) is inspired by the score to Bela Bartok's piece from 1936 *Music for Strings, Percussion and Celesta*. The *Stretto House* translates four movements of Bartok's piece into four separate architectonic sections. The percussion is translated into four brick masses, while the flowing arcs of the roof that connect the brick masses echo the violins. The metallic timbre of the celeste is embodied in the materiality of the metal that clads the roof, and the proportions of the architectural plan are laid out to mirror the proportions of the four-part musical piece (Lutz, 2014). The "Flooded Room" as Steven Holl refers to it, responds to the reverse of the original tonality of the piece that occurs at the end of the work (Holl S., 2012).

The design for the *Parc de la Villette* in Paris (1998) by Bernard Tschumi was inspired and designed with John Cage's *Fontana Mix* in mind. The path as one wanders through the park is similar to the chance paths traveled in the Cage's *Fontana Mix*. The graphic notation of *Fontana Mix* by John Cage is very reminiscent of an architectural plan, showing pathways and circulation amongst a site full of events. The architectural plan spatially echoes this in the design of the red “*Follies*” found throughout the park, responding to the traveled sonic events found in the *Fontana Mix*.

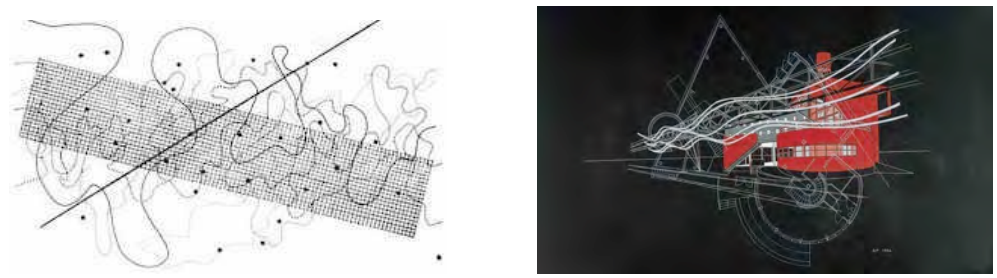
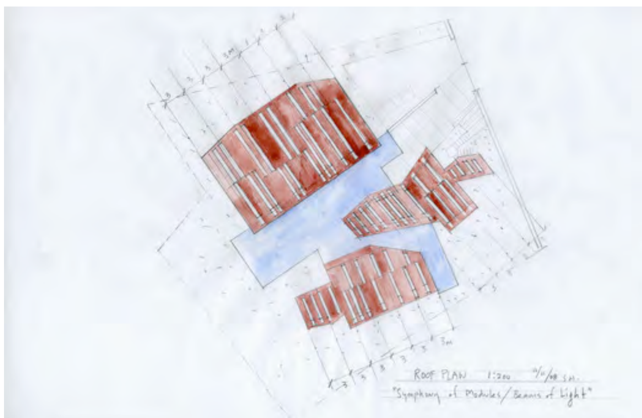


Figure 27: John Cage’s Fontana Mix (1951) & Parc de la Villette by Bernard Tschumi (1987). Images: C.F. Peters Corp & http://www.tschumi.com/projects/3/

Other examples of this relationship can be seen in the *Bloch City* (1983) by Sir Peter Cook. Here a few bars of a concerto by Ernest Bloch is quite literally used as a plan for buildings and roads, extruding the notes as buildings while the musical staff served as roads (Williams, 2009).

Figure 28: Bloch City by Peter Cook (1980) & Bach Monument by Henri Nouveau. Images: (Capanna, 2009) & Bauhaus Archive, Berlin, Germany

The *Daeyang Gallery and House* by Steven Holl (2012) is another example of a score being translated into a building. Here Istvan Anhalt's "*Symphony of Modules*" (1967) score from John Cage's book of graphic scores called *Notations* (Cage, 1970) inspired the building's geometric form (Holl S., 2008).



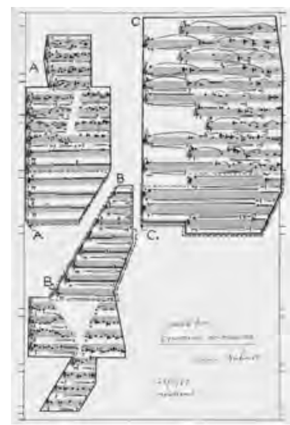


Figure 29: Daeyang Gallery & House by Steven Holl (2012). Images: http://www.stevenholl.com/projects/daeyang-gallery-and-house

We have examined the concept of notation as it relates to the subject and practice of archimusic and presented examples of different projects that have utilized notation and notational qualities in their composition including project. Next, we examine projects that have utilized the trans-disciplinary properties and characteristics of instrumentation to create influential works of archimusic.

2.32 Instrumentation

Instrumentation, similar to notation, is a term commonly found in musical vocabulary. In the context of an architectural conversation, instrumentation is concerned with the spatial, structural, material, or architectonic relationships to performance. The subject of instrumentation as a method of categorization is a bit more involved than the previous idea of notation and is used only as a starting point. It is necessary to provide a more detailed explanation of this category, and in doing so, it will be helpful to refer to ideas found in texts by Jim Lutz and Marcos Novak. In Jim Lutz text, three ways to categorize instrumentation are presented: architecture as *forms & spaces*, *materials & finishes*, and *structure & mechanics*, while Marcos Novak describes another important distinction between *expressive* and *scientific* instrumentation.

In this section, we examine these relationships between instrumentation and architecture, followed by citing specific examples that explain these different relationships by Lutz and Novak and others.

2.321 Instrumentation and Architecture

Instrumentation and architecture is concerned with the spatial, structural, material, and architectonic relationships of expression, performance, and scientific investigation. First, let's discuss instrumentation as a concept and how it can be applied to architectural thinking and making. The discussed integrations (association, translation, and transformation) are found within the topic of instrumentation just as they are found in notation. The notation of a particular work is representative of that which is to be instrumented and vice versa, that which is instrumented will generally have some notational representation.

The concept of instrumentation commonly used in the musical domain refers to the arrangement of certain music parts to individual musical instruments where the composer assigns certain musical parts to be played by specific instruments. For example, if a duet for cello and piano were to play the opposite parts, the piece would take on very different tonality and expression and thus have a different instrumentation. This idea of instrumentation can be applied to the architectural discipline as well. Continuing with the same example, if a building were made of concrete and glass and we were to reverse these materials, resulting in the concrete parts now being composed of glass, while the glass portions are now made of concrete - the building would take on a very different character. These sorts of instrumental experiments can act as viable options to *tune* architecture in order that each piece is playing its correct part and in the right proportion, just as in musical composition.

2.322 Instrumentation and Orchestration

Another essential commonality between architecture and music is the relationship of instrumentation to *orchestration*. Orchestration in the musical domain is a well-understood term and is defined as the "arrangement or direction of a score to produce a desired effect" (Merriam-Webster, 2004). While both instrumentation and orchestration can be thought of as the act of arrangement, it is interesting to note the difference that is explained in a chapter on orchestration and instrumentation in *An Overview of Score and Performance in Electroacoustic Music* (Pasoulas, 2008). "To a large extent, the two words Instrumentation and Orchestration are synonymous. There is a shade of difference, however. Properly speaking, Instrumentation is the personal knowledge of each instrument considered individually, that is to say, of all that we can reasonably ask of it and of all the effects that we can obtain from it. Orchestration is the art of grouping them, playing with them, obtaining timbres of infinite variety from their inexhaustible combinations, and mixing them with one another as a painter mixes the colors of his palette…Instrumentation is a science; Orchestration is an art…The orchestration of a piece of music is like the painting of a picture; the combination of the instruments is like the mixing of colors according to the tint we wish to obtain. Moreover, there is also light and shadow in instrumentation" (Lavignac, 1903).

The act of instrumentation or orchestration is a relationship between the science and art of arranging and organizing a composition, whether it is music or architecture. The more fluid and integral the integration is both scientifically and artistically, the more promise the work has to be influential and push the investigation forward; and indeed, as we will see throughout this research, the most important and influential examples are those that have set out and accomplished a fluid integration.

2.323 Instrument as Architecture: Architecture as Instrument

It is important to illustrate a particular difference between methods that have integrated the notational and instrumental fields of architecture and music in a manner that pushes idea into territory, which simply translates one form into the other. Jim Lutz quotes Daniel Libeskind in his essay "*Transpositions*", saying, "Buildings provide spaces for living but are also de facto instruments, giving shape to the sound of the world. Music and architecture are related not only by metaphor but also through concrete space. Every building I have admired is, in effect, a musical instrument whose performance gives space a quality that often seems to be transcendent and immaterial" (Lutz, 2007) (Libeskind, 2002). This quote represents a powerful perspective that this research is interested in furthering. If the relationship is taken literally, a simple and trivial type of project prevails.

The following projects aim to illustrate this literal translation of instruments as architecture and architecture as instruments. These projects do not engage with the topic of instrumentation as previously discussed. Instead, they engage with the topic of instrumentation in a very literal sense. The first translation, *instruments as architecture* can be seen in the student works from John Hejduk's architecture studio at the Cooper Union that took place during the 1970's and 1980's. In these exercises, students selected an instrument and drew it as an architectural study thus turning an instrument into a building or space (Lutz, 2007).

Another work that can be seen to use conventional instruments and imagine them as buildings is the *Piano Building* in Huainan China by architectural students at the Hefei University of Technology. This project is a literal violin, and a piano scaled up to the size of a building, where the violin is the made of glass and leans against a shiny black skinned piano with glass ribbon windows. An escalator in the violin ascends into the piano that is set up on piloti (its piano legs). Both the Piano Building and Hejduk's design studio exercise a practice that is cheeky, but short sighted. It does not exemplify the conceptual practice and thinking in the interest of this research. However, it is important to note these examples as avenues that have been explored.

The Berlin Philharmonic Orchestra conducted an advertising campaign where the photographer Mierswa-Kluska took pictures of the spaces within certain instruments including a violin, cello, flute, and pipe organ. These photographs make "the tight spaces of these instruments appear grand and spacious considering the true nature of their space" (Naik, 2012).

The inverse translation, *architecture as instrument* can be seen in a collection of musical instruments designed and 3D printed by the Miami Beach architecture firm Monad Studio. Inspired by their use of free-flowing architectural forms, the collaboration with artist and musician Scott F. Hall applied these forms to a series of instruments including a travel bass guitar, violin, cello, didgeridoo, and hornucopia (Del Campo, 2017).

These projects are a few examples of the literal use of architecture and musical instruments and it is important to note that this research is not interested in examining these sorts of literal translations. The interest of this research is to investigate new and more integrative relationships between architecture and music.

The categories and examples in the following section will illustrate integrations closer to the nature of what this research is interested in advancing. As we previously mentioned, the categories that Jim Lutz and Marcos Novak provide in their texts *Transpositions: Architecture as Instrument/Instrument as Architecture* and *The Music of Architecture* respectively, offer a significant step forward in how to think and understand the categories of instrumentation. Next, we examine both of these concepts.

2.324 Forms, Materials, and Structures

In the article *Transpositions: Architecture as Instrument/Instrument as Architecture*, Jim Lutz describes the musical concept of instrumentation and offers three categories to better understand their embodied principles and traits. These are: *Forms & Spaces*, *Materials & Finishes*, and *Structures & Mechanics*.

Forms & *Spaces* are concerned with the physical form and spatial dimensions of an architectural volume, while the *materials* and *finishes* address the qualities of texture and surface. Finally, *structures* and *mechanics* speak to the arrangement and assemblies of the physical parts of the system. In the following paragraphs, we look at each of Lutz's categories of instrumentation and provide examples of projects that exhibit these qualities. Included are some additional examples that fit into Lutz's categories as they address the architectural domain.

Forms & Spaces are concerned with the physical form and spatial dimensions of an architectural volume. Jim Lutz provides the analogy of a violin and its case, which was similarly explored by architects Daniel Libeskind and Steven Holl. Examples of instrumentation as it applies to aspects of *Forms & Spaces* can be seen in the following projects.

- The *Center for Performing Arts* in Fort Wayne Indiana by the architect Louis Kahn uses the concept of instrumentation to its delineation of spaces. The instrument applies to the auditorium while the public hall and supporting spaces are seen as the instrument's case.

- The *Music Box* by Neil Savaige in Halifax Nova Scotia is another example that Jim Lutz provides. Here the expressive ribbon like wooden panels within the auditorium reflects the shape of a string instrument and the S-shaped openings of a cello or violin.

Lutz's category, *Materials & Finishes* addresses qualities of texture and surface. Implementation of this method is usually accomplished by the employment of formalized acoustic physics or, alternatively, through the application of static materials. Here are some of the *Materials & Finishes* projects that are outlined by Lutz:

The *Experience Music Project* or EMP by Frank Gehry in Seattle Washington is a primary example of the material and finishes category. The EMP was commissioned by Microsoft founder Paul Allan, to house his extensive collection of Jimi Hendrix memorabilia. During the design process, Gehry began with broken pieces of Jimi Hendrix guitars and used these to inform the skin and shell of the building. A glass ribbon that looks like an electric guitar's fret board is seen rolling over the building. Additionally, the colors of these guitars were used throughout the design of the building's skin, taking the color blue from the Fender Mustang, red from the Fender Stratocaster, and gold from the Gibson Les Paul.

Figure 30: Experience Music Project by Frank Gehry (2000). Photo: Timothy Hursley

Similarly, the *Walt Disney Concert Hall* located in Los Angeles, also by Frank Gehry, serves as an iconic musical form in the city's downtown. If one asks a tourist “what building in downtown Los Angeles looks the most like a piece of music,” a common answer is often this building. The Disney Concert Hall’s expressive, flowing facade is clad with aluminum metal panels, while the inside of the auditorium is made from Douglas Fir, which is a common material for the construction of string instruments including cellos. These materials were chosen by the acoustician Yasuhisa Toyota for their acoustic and aesthetic qualities, and when Liza Lim was commissioned to compose the opening work for the concert hall, she used this relationship as the inspiration. She states in her essay on the Los Angeles Philharmonic website that the concert hall is “a precisely tuned 'instrument for listening.' One thought I had about connecting the orchestra to the hall came from observing things on a physical or material level” (Lim, 2004). Her composition *Ecstatic Architecture* (2004) contains brass and horns that reflect the expressive nature of the external metal cladding, while the strings echo the soft wooden paneling of the auditorium.

Figure 31: Disney Concert Hall by Frank Gehry (2003). Image Courtesy of Gehry Partners, LLP

Instrumentation in the form of Lutz' *Structures & Mechanics* speaks to the arrangement and assemblies of the physical parts as a system. The structural and mechanical category is exemplified in both the *Luminous Veil* project by Dereck Revington and the *Chord Bridges* by Santiago Calatrava.

- The *Luminous Veil* by Dereck Revington runs along a bridge outside Toronto, Canada. Designed to be a suicide barrier, it incorporates long cables that run the length of the bridge's edge. The cables produce a vibrational hum sound when the wind blows across the bridge and is inspired by the haunting and mournful tonality of Mozart's *Requiem*.

Across the Atlantic in Hoofddorp, the Netherlands, three bridges named the *Harp*, *Lyre*, and *Lute* by the architect and engineer Santiago Calatrava are inspired by the structure of string instruments due to their suspended cable constructions and shape. Similarly, Calatrava *Chords Bridge* in Jerusalem is designed to resemble a harp, referencing the *Kinnor* of King David and the instrument representative of the Israeli People (Press, 25).

Figure 32: Chord Bridges by Calatrava Hoofddorp (1999-2004) Jerusalem (2008).

Image: www.helvar.nl/ and Yanky Weiser

- The *Panopticon: Singing Ringing Tree* by the architecture firm Tonkin Liu sits atop a windy hill in the UK and uses stacked panpipes. The pipes are scaled from the shortest (highest pitch) on the bottom to the longest (lowest pitch) on the top and spiral to create a tree-like shape. When the wind passes through the various static pipes, a chorus rings out across the hillside.

Figure 33: Panopticon: Singing Ringing Tree by Tonkin Liu (2004).

Image: Tonkin Liu

- The *Sibelius Monument* or *Passio Musicae* in Helsinki Finland by Eila Hiltunen is dedicated to the Finnish composer Jean Sibelius, for whom the score-writing program *Sibelius* is also named. This abstract sculpture, like the *Singing Ringing Tree*, is made of 600 steel pipes and shaped to create a wave pattern, also creating droning tones as the wind blows across the flutes.

Both the *Singing Ringing Tree* by Liu and the *Sibelius Monument* by Hiltunen have a significant relative from the past. In the mid-17th century, Athanasius Kircher developed a design for an Aeolian harp of similar proportions and scale. The long, symmetrical, trumpet-like form funneled, blowing wind across strings located in the center, between the open ends, sounding a resonating hum into the landscape. Kircher also designed some awe-inspiring architectural spaces using similar techniques.

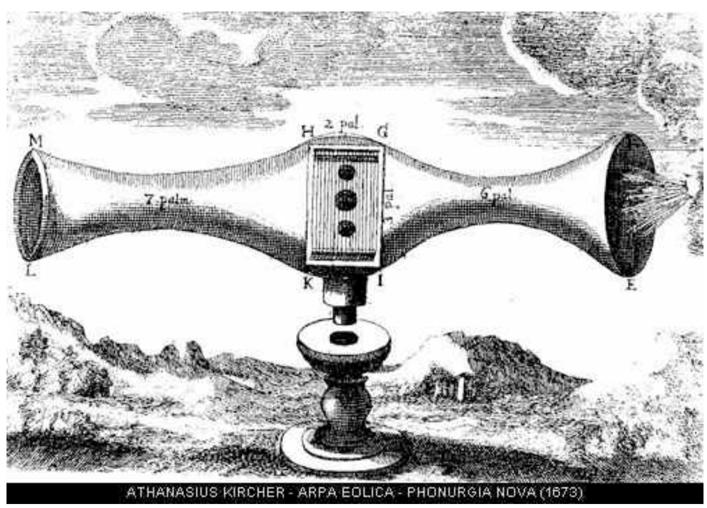


Figure 34: Aeolian harp by Athanasius Kircher (1646). Image: (Kircher A., 1966)

2.325 Scientific and Expressive

Next, we examine Marcos Novak's *scientific* and the *expressive* categories, which he outlines in his essay *The Music of Architecture*. These represent the expressive and scientific functions that instrumentation has within the realm of archimusic. The scientific "allows us to peer into worlds beyond our normal senses to bring patterns beyond normal recognition," while the expressive "extends the expressive domain of an individual, achieved by an apparatus that allows a high degree of control over some aspect of the sensory world" (Novak M., 1992). We can think of such works as positioning themselves as places for the performance of music and the inquiry into music. First, both of these concepts relate to architecture or space as a place for the engagement, performance, and experimentation of music, resulting in an architecture that affects the music in a way that would be significantly different if set in a different place. Because of the nature of the acoustic properties, such as reverberation, every space will sound different; the distinction that is important to understand is that the space and the sound have a relationship that is inherently linked, and because of this unique link, extraordinary events happen. Spaces such as concert halls and performance venues are found to have this relationship.

The expressive is concerned with performance qualities and aspects that engage the sensual and intellectual qualities of the reception of music including perception, psychoacoustics, and bio-musicology. Novak states that an expressive space can be “played with virtuosity” (Novak M., 1992) and is part of the qualitative approach of a musical space or sonic space, which we will cover in the following section.

The *Walt Disney Concert Hall* in Los Angeles by Frank Gehry, the *Boston Symphony Hall* by McKin, Mead and White and the *Bayreuth Festspielhaus* in Germany by Gottfried Semper and Richard Wagner are examples of expressive instrumental integrations. As previously described, the *Disney Concert Hall* uses Douglas fir for the interior of the music chamber, while the expressive metal-clad outside symbolizes a musical reference of the brass family. The *Boston Symphony Hall* has what many consider the best acoustic properties for the performance of music (Jr., 2005). Wallace Sabine who is deemed the father of architectural acoustics (Britannica, 2003) (and for whom the *Sabin* (unit of sound absorption) is named) was the acoustics expert on the project and created one of the very first concert halls to be designed using quantitative acoustic methods.

Figure 35: Boston Symphony Hall by McKin, Mead, White and Sabine (1900).

Image: https://commons.wikimedia.org/wiki/File:Boston_Symphony_Hall.jpg

The *Bayreuth Festspielhaus* in Bayreuth Germany is another excellent example. Based on an unbuilt design by Gottfried Semper (Mallgrave, 1996), the *Bayreuth Festspielhaus* was built in 1876 for the sole purpose of the performances of Richard Wagner's work and played a vital role in the avant-garde of early modern opera. The orchestra pit was designed to Wagner's specifications, enabling him to stage new types of performances with the audience's primary focus on the stage; he did this by reorganizing and visually shielding the orchestra using a visual shield and by rearranging the layout of the orchestra.

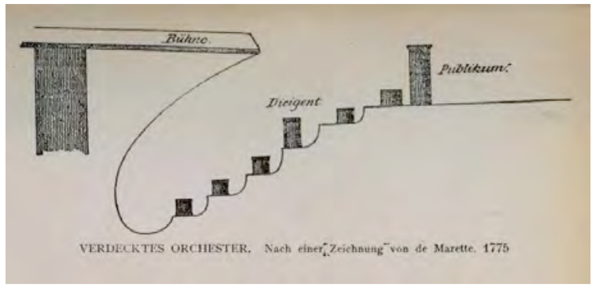


Figure 36: Bayreuth Festspielhaus for Richard Wagner (1876). Image: http://www.lexikus.de/bibliothek/Bayreuth

The scientific or quantitative perspective is where an architectonic structure is meant for the study of a sonic component or effect. This perspective as Novak states, “allows us to peer into worlds beyond our normal senses, to bring patterns beyond normal recognition… enlarging the world we live in without disturbing the occupant…and return information about inaccessible parts of the world…as a telescope and microscope does” (Novak M. , 1992).

Exemplifying of the scientific, architectural, and musical integration are the *Espace de projection* (ESPRO) at *IRCAM* in Paris and the *AlloSphere* at UCSB in Santa Barbara. These two spaces are designed as spatial instruments for the investigation and experimentation of spatial sound. The *Espace de projection* at IRCAM is a large hall with walls and ceilings capable of changing its surfaces between three different absorbent materials, and the size of the space can be adjusted. The *AlloSphere* at the UCSB is a three-story high perforated black sphere inside a nearly anechoic chamber with a 55.1

channel Meyer Sound system arranged in three circles within the sphere (Amatriain, 2009). These spaces are designed and constructed for the analysis and evaluation of sound within a particular scientific spatial context.

Figure 37: The AlloSphere at MAT (2007). Image: http://www.allosphere.ucsb.edu/

Instrumentation, like notation, illustrates the inherent relationships between architecture and music and is an essential facet of the archimusical. The previously discussed categories can assist in organizing and understanding past works that have explored the intersection between architecture and music as will be seen in future sections. Together, these different methods can be used as a model for understanding how future works related to this interdisciplinary field can be approached in novel ways.

Next, we look at the concepts of spatial sound and sonic spaces. These trans-disciplinary relationships incorporate the previously mentioned concepts of notation and instrumentation into modal forms that have pushed the interconnectedness of architecture and music forward.

2.34 Spatial Sound & Sonic Spaces

In the past sections, we looked at the various ways that notation, instrumentation, and computational systems have informed the relationships between architecture and music. These relationships concentrate on representation and the physical translations of musical and architectural works. Next, we will look at the embodied modalities of spatial sound and sonic spaces, which explore the relationships between architecture and music as a spatial and sonic approach. The role of representation and instrumentation are still found within these new embodied integrations, but the single most important distinction to be made is this: *the end product is not wholly a work of music or architecture, but rather it embodies concepts and characteristics from both fields and unites them into a hybrid archimusical form.*

In the following paragraphs, we introduce examples of these spatial sound and sonic spaces as methods that unify the modalities of space and sound and illustrate their close inter-connective nature. We provide examples of works that exemplify the usage of both space and sound, which have influenced the field and have contributed to unifying the two fields and creating works of a hybrid nature.

2.341 Space and Sound: Multi~, Cross~, Inter~,

Spatial sound and *sonic spaces* encompass the two directions of information flow between the modalities of space and sound. When space and spatial concepts inform the role or capacity of sound, then *spatial sound* is generated (Space into Sound = Spatial Sound). When sound and sonic concepts inform the capacity of space, then *sonic space* is generated (Sound into Space = Sonic Space). These categories offer a general insight into a manner of thinking about the reciprocal relationships and the different integrations of the modalities of space and sound.

When the disciplines of architecture and music are used to create works of *spatial sound* and *sonic spaces* the relationship between them becomes integrated in a new way. The associational relationships that are *multi*-disciplinary and the translational interpretations that are *cross*-disciplinary, which we have used exclusively up to this point, begin here to evolve into *inter*-disciplinary integrations (Figure 2.). Here the modality is a hybrid, an embodiment of both spatial and sonic components acting together. Composers such as Karlheinz Stockhausen and Edgard Varèse along with architects and artists such as Iannis Xenakis and Bernhard Leitner made essential contributions to these hybrid modalities and created insightful and genera-advancing new works of archimusic.

2.342 Spatial Sound

Spatial sound, or the spatialization of sound, is an academic and practiced professional field of its own. *Spatial sound* has an interesting history that can be dated back to the vernacular call and response work songs of sailors and early antiphony church choirs. It is more recently understood, researched, and practiced in the field of electroacoustic, electronic, and computer music where sound and music is composed with the purpose of localizing sound sources in space (Roads, 1996). Since the advent and use of the loudspeaker, electronic synthesis and computer music in the 20th century, spatial sound explorations have been developed by composers.

Charles Ives's *Fourth Symphony* (1912–18) and Rued Langgaard's *Music of the Spheres* (1916–18) are two examples from the early 20th century that utilize the dimensions of space within their orchestral compositions. Other significant works of spatial sound include Edgard Varese's *Poème électronique* inside the Phillips Pavilion, Karlheinz Stockhausen's *Gesang der Junglinge* in 1956, John M. Chowning's *Turenas* in 1972, and *The Simulation of Moving Sound Sources* in 1977. Iannis Xenakis' *Hibiki Hana Ma* inside the Japanese Steel Federation Pavilion at the 1970 *World Expo* in Osaka Japan and Curtis Roads' *Spatialization of Sound Particles* in 2001 also offer significant advancements to the compositional techniques and processes, as we will describe in the following paragraphs. These works utilize spatial sound in different compositional genres including, *orchestral*, *electroacoustic*, and *musique concrete*.

Edgard Varèse's *Poème électronique* commissioned for the Philips Pavilion at the 1958 *World's Fair* in Brussels, was another exemplar of spatial music. *Poème électronique* embodied Varèse's concept of *organized sound.* By using a custom switching mechanism, the composition (which was on multi-channel tape) was spatialized through hundreds of speakers arranged throughout the nine hyperbolic parabolas of the pavilion.

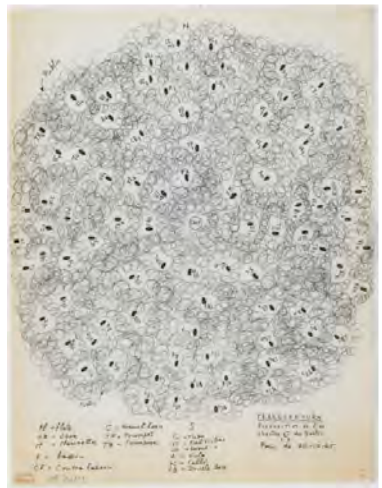


Figure 38: Terretêktorh by Xenakis (1965). Image: Iannis Xenakis Archives, Bibliothèque Nationale de France

Terretêktorh by Iannis Xenakis is another spatial sound composition that uses an orchestra. *Terretêktorh* was inspired by sounds found in nature and composed by creating paths of sound woven in space. For the performance, Xenakis placed the orchestra members and their instruments throughout the audience, allowing a tone or sonic event to travel from one space to another, in front of, behind, or straight through the audience's space (Hofmann, 2005).

Karlheinz Stockhausen's 1968 spatial composition *Musik fur ein Haus* is an example of spatial music that is integrated into an architectural setting. In this work, musicians performed inside one of four different rooms on two different floors of a house. Visitors could wander through the different spaces and experience the sonic composition as if it were in a gallery or museum setting (Iddon, 2004). Microphones placed within each room picked up the music being played and projected it through loudspeakers in the other rooms. Within a fifth room of the house, one could hear the recorded music from all four rooms simultaneously.

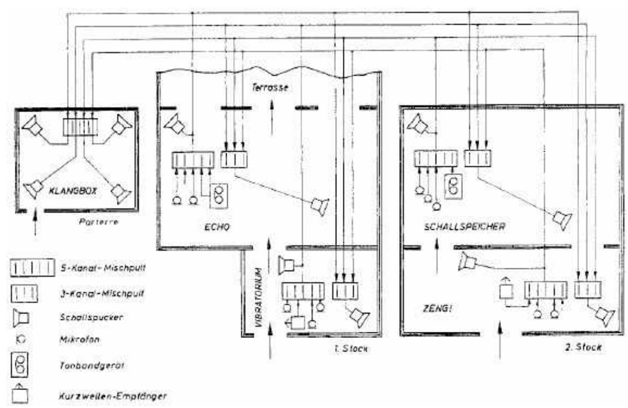


Figure 39: Music fur ein Haus by Karlheinz Stockhausen (1968). Image Karlheinz Stockhausen

Stockhausen describes his space specific compositions as, “requiring a very special kind of architecture” (Forsyth, 1985) where spatial music is integrated into architectural spaces specifically designed for a compositional purpose. These site-specific spaces described by Michael Forsyth, are new designs for music houses that require particular types of architecture made specifically for these site and spatial specific compositions. One of these spaces Forsyth outlines is made of, “Several small auditoriums each for a particular kind of music…Polyphony of musical characters, even a

Polyphony of styles" and a "space where two orchestras would be divided by a wall with mirrors on each side allowing only the conductors of the two orchestras, not the players, to see each other. A listener wanders through a space hearing a multilayered composition as if one were walking through an enormous enlarged score where the experience might be compared to the paintings of Bosch" (Forsyth, 1985) (Cott, 1974).

2.343 Sonic Spaces

Sonic Spaces are less well-known than *spatial sound* as an independent form of expression and are understood more as actualized environments that are generated by the design of spaces where sound is a key spatial parameter.

Designs similar to those of Stockhausen's can be found dating back to the 1600s. Prominent among these historical examples are projects by the 17th-century philosopher and polymath Athanasius Kircher. In Kircher's design for a museum (Kircher A., 1970), statues would appear to be speaking by means of directing and altering the sounds from adjacent spaces (both interior and exterior) funneled to the statues' mouths. Other rooms utilized architectural acoustic techniques to bounce the collected sounds off arched ceiling surfaces and toward the statue's bust.

A more active approach, in comparison to the ambient nature of the previous example, is presented in Kircher's *Organ* (Kircher A., 1970), where we can see the overall space being used as an instrument, in a manner quite different from the instrumental examples we covered in the previous section. The architectural space is integrated with a complex mechanical, water-powered, barrel-operated pipe organ, innovative and novel for its time.

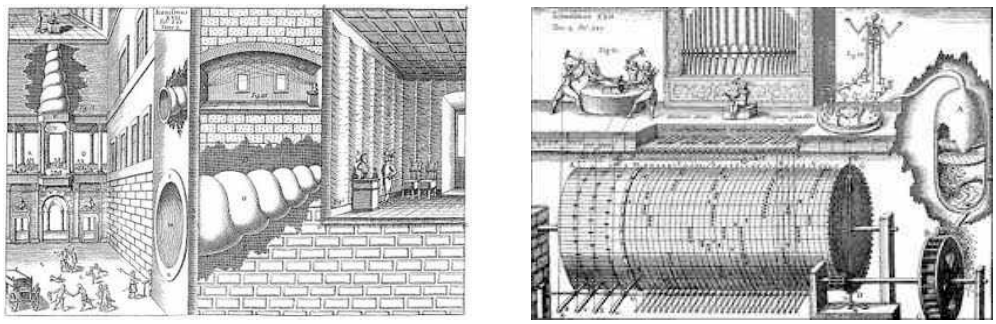


Figure 40: Sound Amplifier (1647) & Organ (1646) by Athanasius Kircher. Image: (Kircher A., 1966)

The *Philips Pavilion,* is also a very influential example of a *sonic space* which integrates spatial sound in an architectural setting. As previously mentioned in Edgard Varèse's *Poème électronique*, the pavilion itself was instrumental in both the design of a musical composition and the relationship to the architecture's characteristics. The structure was influenced by the graphic notation of Xenakis' *Metastasis* (1954) acting as a physical embodiment of the music itself, and was developed for Xenakis' *musique concrete* composition *Concrete PH* (1958).

Figure 41: Philips Pavilion by Xenakis & Le Corbusier (1958). Image: fondationlecorbusier.fr

Stockhausen's spatial compositions and his designs for purpose-built architectures for the performance of new compositions can be seen and appreciated in the West German Pavilion at the 1970 *World Expo* in Osaka Japan. Inside a geodesic dome designed by the German architect Fritz Bornemann, Stockhausen spaced 50 groups of loudspeakers within the sphere, including below a suspended floor. The spherical space completely surrounded the 550-person audience and enabled them to experience the three-dimensional spatial compositions of *Spiral* and *Short-Wave Receiver*. As Forsyth points out, Stockhausen used a "specially designed rotary sound mill" (Forsyth, 1985), which had electronic contacts that when connected distributed the sounds from one speaker to another, allowing the audience to "experience the sound rotating and spinning in horizontal, vertical, diagonal, clockwise, counterclockwise and spiral formations." This allowed, "Multiple sound sources could be made to swirl along arbitrary trajectories, intersecting and interweaving each other" (Cott, 1974). "The conductor-composer controlled the audience's experience by turning knobs rather than by moving a baton" (Blesser, 2009). This one-of-a-kind experience created polyphonic layers of sound specifically placed to create sonic forms. Multi-track tape compositions from Bernd Alois Zimmermann and Boris Blacher were also performed within the space during the six-month exhibition.

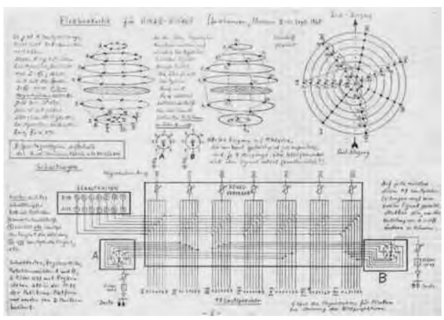


Figure 42: World Expo German Pavilion by Fritz Bornemann and Karlheinz Stockhausen (1970). Image: Karlheinz Stockhausen

The 1970 *World Expo* in Osaka, Japan was a focal point for the exploration of *new spaces designed for music* and *new music composed for spaces*, especially using electroacoustic technology under the theme of *Progress and Harmony for Mankind*. Barry Blesser describes the *Pepsi-Cola Pavilion*, describing how it was "was configured as an electronic space that could take on the different personalities of the composer. It used 37 loudspeakers and 8 signal-processing channels, which provided amplitude modulation, frequency modulation, and spectral filtering. The music source was a combination of 16 monophonic tape-recorded channels and 16 microphones for live performers. Electronics were changing, creating, and projecting sounds into the space" (Blesser, 2009).

Iannis Xenakis illustrated a similar approach in his composition *Hibiki Hana Ma* also at the 1970 *World Expo* in Osaka, Japan, and exhibited in the *Japanese Steel Federations Pavilion*. Here Xenakis used his *stochastic* methods and "800 loudspeakers grouped into 150 independent groups and positioned through the air and in the ground" (Xenakis I., *Music and architecture: architectural projects, texts, and realizations*, 2008) to spatialize 12-channels to creating intricate sonic shapes amongst the audience.

Sven Sterken notes in his essay *Music as an Art of Space* that Xenakis' interests in the relationships between space and sound, which he had been exploring for nearly 20 years were still focused and deliberately connected to the field of architecture. "Assuming that the ear can provide us with spatial orientation just as much as the eye" (Sterken, 2007), Xenakis argues, that these manifold loudspeakers should be considered as geometric points, and that by consequence "all that is true for Euclidian space can be transposed into acoustic space." Consequently, abstract morphological sound patterns such as geometric shapes and surfaces can be articulated in space and recognized by the ear. Sound is not only a carrier of musical expression, but also a means to expand the boundaries of architecture through the creation of immaterial and dynamic spaces. In other words, in Xenakis' perspective, the acoustic grid was not only a highly sophisticated sound projection system, but a device to generate ephemeral architectures and virtual spaces." Sterken continues this thought by stating, "Besides being a means to explore or create spaces, the dispersion of musicians and sound sources also has to do with Xenakis' philosophical views on music. One of the implications of this technique is that the audience no longer hears one single, homogenous sound; everyone literally hears the music from a different angle" (Sterken, 2007). As Xenakis has suggested, "this mode of listening somehow resembles the way one perceives a building" (Iliescu, 2000).

Bernhard Leitner is a sound artist and composer that has explored the relationship of sonic spaces and has "pioneered in the conceptual area where architecture, space, and sound come together" (Harris, 2002). Perhaps one of the best examples of his works is *Le Cylindre Sonore* in the *Parc de la Villette* in Paris. This double-walled concrete cylindrical form is placed within the natural setting of a bamboo grove with bilateral access. Once inside there are eight sound columns embedded within the 15' high walls of the form, each with three speakers. Visitors can sit or wander and experience the meditative drone-like atmospheric soundscape resonating within the walls of the chamber.

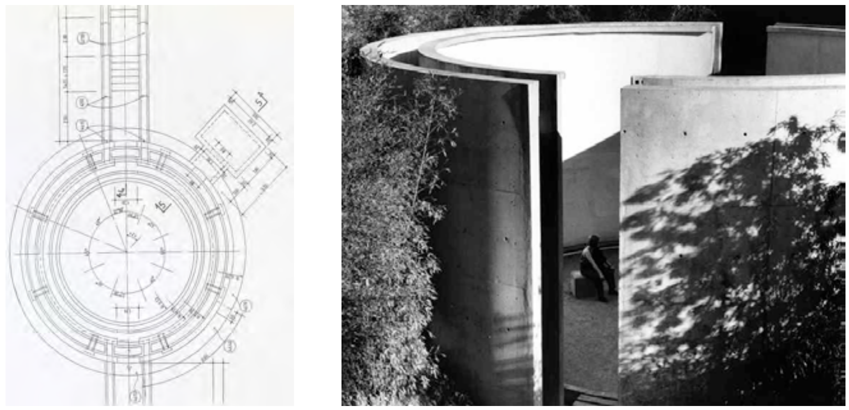


Figure 43: Le Cylindre Sonore by Bernhard Leitner (1987). Image: Bernhard Leitner

Leitner's *Le Cylindre Sonore* is not alone in its home within the *Parc de la Villette*. In fact, the *Parc de la Villette* is home to a number of archimusical projects that we have described in the past few sections. These include Bernard Tschumi's *follies*, which were designed in dialogue with John Cage's graphic score for *Fontana Mix* and Xenakis and Jean-Louis Véret's design for the *Cité de la Musique*, which was never realized but would have expanded the field of archimusic.

Other works by Leitner illustrate similar interests of Stockhausen's *West-German Pavilion* where the regular layout of sound sources enable sounds to travel and create virtual paths around the user. One example is *Soundcube* (1969), which was a cube with 64 sound sources that would allow the sound to travel, sequentially creating many paths guiding the visitor's curiosity (Bernhard, n.d.).

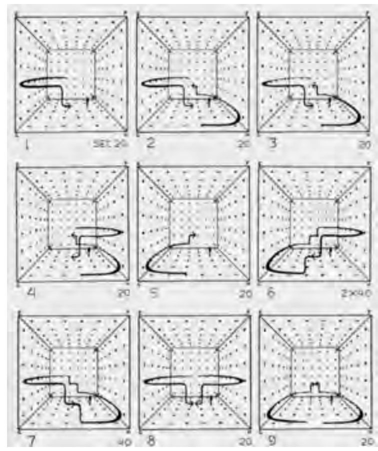


Figure 44: Soundcube by Bernhard Leitner (1969). Image: Bernhard Leitner

2.344 Environments and Places

Though most of the examples we have discussed are concerned with a human-made or constructed architectural setting, spatial sound can be designed for environments that are more naturally occurring as well. One early example of a sonic work composed for the open and natural environment was *The Universe Symphony* (*The Earth and the Filament*) composed between 1911 and 1928 by Charles Ives. Michael Forsyth describes *The Universe Symphony* in his book *Buildings for Music*, by saying the symphony, "would have spread over the entire landscape, with groups of musicians gathered on hills and in valleys to sound a joyful disordered freedom" (Forsyth, 1985). This compositional concept came to fruition 50 years later in two of Iannis Xenakis' *Polytopes*, *Polytope Persepolis* (1971) and *Polytope de Mycenae* (1978). These audio, visual, and performance compositions took over the landscape and employed both electroacoustic and traditional instruments in the natural setting of the *Temple of Darius* in Persepolis, Iran and the ruins of *Mycenae*, in Greece, respectively.

The *Jeita Grotto* served as the performance space for some of Stockhausen's works, including *Stimmung* in 1969. Located in an expansive cave in Lebanon, Stockhausen created a spatial sound experience consisting of electroacoustic music on tape and orchestra members spaced throughout the space. The reverberation times of eight seconds and the natural rock formations were said to create a mysterious experience. Much of this is due to the unusual natural forms that may be considered on the opposite side of the spectrum between acoustically tuned concert halls and that of a natural or fractal space tuned to the resonating body of the Earth.

We have explored the concepts of notation and instrumentation, and presented examples of projects, which have exhibited unique ways of incorporating scoring and drawing. These projects have influenced new directions in the composition, design, and practice of archimusic and provided the notational and instrumental foundation, which is a key component of archimusic. The disciplines of architecture and music embedded within each other also form spatial sound and sonic spaces whose architects and composers found inspiration and insight when designing and composing new and compelling works, which paved new ground in relating these two fields. The role of archimusic, as we intend to push forward, is found within these sorts of integrations where the two disciplines unite to become a third new form. These understandings and relationships found in each discipline can be related to the other in unique and significant ways and allow the end work to generate very different aspects of both arts due to the integrated cross and interdisciplinary approach. This overlap will continue to give rise to interesting thoughts and ideas that mature and develop, leading the world into insightful and promising territory.

2.35 Additional Integrations

In the following paragraphs, we briefly discuss additional relationships that offer further perspective and understanding of the connection between architecture, music, space, and sound. These include *aural architectures*, *soundscapes*, *architectural acoustics*, and *sound sculptures*.

2.351 Aural Architectures

Aural Architecture is a term used by Dr. Barry Blesser, a former MIT professor, one of the founders of digital audio (with his 1978 paper *Digital Processing of Audio Signals*), and co-chair of the first *International Conference on Digital Audio* in 1980. Dr. Blesser has published widely on these topics, including a recent book written with Dr. Linda-Ruth Salter entitled *Spaces Speak, Are You Listening?* and an essay in OASE entitled *Aural Architecture: The Invisible Experience of Space*. These two writings describe the exploration of spatial awareness from the auditory perspective, and the relationships between our auditory sense and the natural and built environments. Blesser states, “all sound exists in a space; there is no spaceless sound” and "*Aural Architecture* is concerned with the experience of sounds that have been changed by the physical properties of a space.” Since there is no "spaceless sound” (this refers to the cultural, mental and physical ideas of space and sound), we can then discern that *Aural Architecture* is in fact concerned with all sounds, in and so far, as they are concerned with space. What exactly is *aural architecture* and how does one understand, or design with these "sound changes" by "physical properties of space?” To understand *aural* architecture, Blesser states, "compare it to *visual* architecture” although he goes on to say the terms will not always work because our visual vocabulary is much more developed than our sonic one (Blesser, *Aural Architecture: The Invisible Experience of Space,* 2009). This is heavily due to the visio-centric relationship that has been nurtured in our culture since modernity.

The Finish architect Juhani Pallasmaa discusses this visio-centric relationship at great length in his book, *The Eyes of the Skin: Architecture and the Senses,* promoting a perspective that focuses on architecture and senses other than vision, especially touch and hearing (Pallasmaa, 2012). These ideologies are explored further in Pallasmaa’s writings *The Thinking Hand* where Juhani discusses the disconnection of the visual and the virtual (Pallasmaa J, 2009). These perspectives help to inform the relationship of space to other modalities such as sound which support the direction of this research.

Bissera Pentcheva uses the term aural architectures as well. Her interests are at the intersection of acoustics, religious, sacred spaces, and architectural psychoacoustics. She runs a project called *Icons of Sound* (Pentcheva, n.d.), which examines reverb time estimation, multi-sensory aesthetics, and contextual psychoacoustics within the Hagia Sophia. These individuals along with other researchers from the disciplines of architecture, music, and acoustics (amongst other disciplines) are discovering similar integrations between sound and architecture in fascinating ways.

2.352 Soundscapes

A *soundscape* is an *acoustic ecology* arising from an *immersive environment* and can exist in both natural environments and in human-made or altered environments. This term was coined by R. Murray Schafer, and is discussed at length in his book *The Soundscape: Our Sonic Environment and the Tuning of the World* (Schafer, 1993). It is important to note that soundscapes are perceptually bi-directional; meaning, they can be both captured by recording an existing environment (a mountain meadow on a summer's eve, or a boulevard in an urban center during rush hour) or generated to project a certain quality into a space (*Muzak*, and meditation and sleep apps, for instance). Soundscapes can also be combined or mixed to give sonic resolution, cues to the visually impaired or as ambient background, for example. Many artists have experimented with soundscapes as an artistic, musical, or compositional endeavor, including John Cage, R. Murry Schafer, Luc Ferrari, and Max Neuhaus. Schafer discusses sounds and their relationships and to life from the beginning of human experience to the natural environment of the rural, social, cultural, industrial and electrical evolutions that have followed. Thus, soundscapes are found in existing environments (i.e. a mountain meadow on a summer's eve), or from a human-made environment (i.e. a boulevard in an urban center during rush hour).

The recording, altering (speed and direction) and composing of these natural and human-made sounds was first seen in the *acousmatic* music field of *musique concrète*. Pierre Schaeffer pioneered the field of *musique concrète*, composing the first piece of recorded music entitled "*étude aux chemins de fer*" and began working with recording, looping, and mixing sampled sounds together. Later, composers such as Stockhausen, Varese, Xenakis and many of the early electronic composers of the 20th century would follow suit, some even studying with him, as in Stockhausen's case. Together they contributed material, methods, and knowledge about working and composing with recorded content from both the natural environment (*Concret PH* by Xenakis), the built environment (*Étude aux Chemins de Fer* by Schaeffer), abstract composition (Etude by Stockhausen) or more recent interactive examples (*Radio Net* by Neuhaus). Soundscapes are sonic worlds, telling stories, providing indicators, and giving sonic resolution to a traditional context or space; they can give the sense of place to the raw material of space.

2.353 Architectural Acoustics

The word acoustics is derived from the Greek word *ἀκουστικός* (akoustikos), meaning "of or for hearing, ready to hear" and that from *ἀκουστός* (akoustos), heard. Wallace Clement Sabine is the father of modern architectural acoustics (Proc.I.O.A. Vol. 21 Part 6), though the ideas of architectural acoustics date back to the ancient Greeks. The *amphitheater at Epidaurus* by Polykleitos the Younger is an excellent example, which illustrated a mastery of acoustics. From the stage, the spoken word can be heard throughout the entire space, using only geometric configuration for amplification. Another example is Athanasius Kircher's museums with talking statues discussed earlier.

There are instances of inherent sonic effects within spatial environments. The natural echoing effects of the *Whisperings Arches* at Grand Central Station in New York City or at Grand Central Station in St. Louis, both create a hidden sonic gem, captivating once discovered, especially if by surprise. However, this relationship still exhibits an interactive connection between the space and sonic effect within the preeminence of architecture.

2.354 Sound Sculptures

Sound-sculptures are interdisciplinary works in which a sculptural form produces sound. These can be seen in the realms of fine art and architecture, and though they may have similar qualities, sound-sculptures are considered more sculptural than spatial. John

Greyson outlines many examples in his book *Sound-sculpture: a collection of essays by artists surveying the techniques, applications, and future directions of sound sculpture*, which is a great resource within a field that is otherwise little documented. Examples of sound-sculptures can be seen in the works of Bill Fontana such as *Harmonic Bridge*, *Sonic Mappings*, and *Spiraling Echoes*. Site-specific sound-sculptures can also be seen in the *Blackpool High Tide Organ* by artists Liam Curtin and John Gooding and the *Sea Organ* in Croatia by Nikola Basic. These two projects are located next to the sea and use the dynamic of the tides to produce sounds. The previously discussed *Panopticon: Singing Ringing Tree* can also be seen as a sound-sculpture.

2.4 Composition, Computation, and Design Systems

We have *presented and discussed at length the relationships of notation, instrumentation, spatial sound*, and *sonic spaces*, selected projects that have contributed to this interdisciplinary field, and the exemplary architects, composers who made them. We have also discussed *how* these works have been developed and *what* artifacts that have been produced as a result of the interdisciplinary processes and integrations. In the following section, we address the concepts of computation and its relationship to the musical and architectural compositional process, standardization, and we conduct a survey of contemporary computational design programs that helped advance compositional techniques.

2.41 Computation and Composition

The topic of *composition*, as it applies to the visual and aural arts, is the arrangement of elemental relationships that aim at “placing together” a complete whole. In this research, composition is approached using computational means and processes. Marcos Novak contributes an important perspective in his essay, *An Experiment in Computational Composition* stating, “*with the advent of parametric design, and with grammatical or other knowledge-based approaches, the issue of how to use computation to determine proportion becomes very important. The present paper attempts to revive the issue of proportion in architectural composition, and suggests that the multitude of approaches used throughout history may have been approximations to a much more fundamental concern, the provision of adequate visual information to demand, and sustain, visual interest*” (Novak M., 1989). Within composition, the topic of proportion is a significant interest, and with the use of computation, we will explore novel proportional relationships.

Computation and composition are integrated within the digital realm of both musical and architectural design and the notational and instrumentational processes. With graphic notations and multimodal instrumentations, unending compositional variety can be achieved by using different translational and transformational methods. Many of the known methods developed by the architects and composers for their own designs, such as those by Stockhausen and Xenakis, achieve unique expressions of the discussed associational, translational, and transformational integrations.

2.42 Standardization and Possibilities

Regarding composition and its relationships to notation and instrumentation, we can consider two cases. In the case of music, it is familiar practice for a piece of music to be performed by more than one person, with each musician employing a different instrument. Likewise, in the case of architecture, it is common that the realization of a building (akin to musical performance) involves the performances of many people from many disciplines. This coordinated effort is possibly due to sufficient and well-understood standardization, so that both music and architecture are universally playable (in the case of music) and buildable (in the case of architecture). While this is standardization is enabling, it is also restrictive, so it comes as no surprise that practicing members of both disciplines have wished to explore and produce work that steps outside the boundaries of conventional standardization. However, if a work is composed or designed too far outside of understood norms, it becomes difficult to know to what degree the work, when built or played, will resonate with the intentions of its creator. Examples of stepping outside conventional boundaries can be seen in the work of Earl

Browne’s *Folio* and *four Systems* (musical domain) and Daniel Libeskind’s *Chamber Works* (architectural domain). These are inspired and respected works, though the results obtained by performer interpretations can vary widely.

The representative notations, whether an architectural drawing or musical score, for instance, must be replicable and can exist in slightly different, partial, or incomplete forms. In his book *Intentions in Architecture,* Christian Norberg-Schulz identifies this as “*concretization,*” meaning that though a project can be represented in different ways, the totality of a work exists in the finished form. Different methods of representation offer factors of compositional interest, such as those that Nelson Goodman describes as *autographic* and *allographic*. In his book, *Languages of Art: An Approach to a Theory of Symbols*, Goodman explains the terms *autographic* and *allographic* in relation to forgery, but it is instructive to note how these terms apply to the notational forms of architecture and music. A musical score or written poetry can exist undiluted in numerous *allographic* copies, each copy still containing the work’s original essence, but a painting cannot (Goodman, 1968). Each is a notation, but in the case of the painting the notation is the only authored, *autographic*, form. The musical score and the architectural drawing can be considered *allographic*, existing in the same way that *allographic* copies of an original poem are part of the purpose and nature of the final form of that poem.

For the purposes of this dissertation, the relationship of authenticity and individuality to the new forms generated within the realm of the proposed *archimusic* will be primarily *allographic*, though the ability for an *allographic* process to generate *autographic* works provides interesting directions for future work.

Standardizing these *allographic* relationships has led to breaking from conventional norms and transformations within initial disciplines into possibilities previously only available to other disciplines. Andrew Lucia and Jenny Sab, in the conclusion of their essay, *Rethinking the Role of Xenakis* state, "to standardize notation is to standardize patterns of thought and the parameters of creativity. Our present abundance of notations is as it should be. It makes our differences more clear" (Sab, 2014). It is not the intention of this research to claim previously mentioned experiments are wrong and hold the discipline back in any way. In fact, the very reason we still know about them is a testament to their ongoing validity. While the tension between standardization and individuality must be contended with, it is important that new notational systems be created and that current conventions be bent, stretched, and perhaps even broken.

2.43 Computational Design Systems

Throughout the latter half of the 20th century and to the present day, the computer has become integrated into nearly every field. The role of computation has allowed the disciplines of music and architecture to achieve new heights and enabled spectacular developments regarding composition and application. For designers and composers who explore new forms using generative algorithms, computation and software applications offer great advancement for the generation of compelling compositions. These contemporary advancements have been facilitated by so-called *digital signal processing* (*DSP*).

As the term implies, *digital signal processing* is the processing of signals that have been converted from an analog to a digital representation for the sake of computational treatment. A signal is a gesture, action, or sound that is used to convey information or instructions, typically by prearrangement between the parties concerned (Merriam-Webster, 2004). A signal can be either an analog or digital source (Roads, Microsound, 2004) and represent information from such sources as sound pressure, waves, voltage, or electrical activity. Such signals can be sampled and quantized from a given signal source for their use in measuring certain quantities that are representative of specific qualities or characteristics of the signal source.

Sampled signal data can be graphed or visualized in a few different ways. One common way is as waveforms representing the magnitude of incoming signals unfolding in the so-called *time domain*. Another is representing signals in so-called *frequency domain* using what is known as a *Fourier transform*. *Fourier analysis* enables the conversion of a sampled signal from its original *time domain* representation into one in the *frequency domain* and vice versa. The *Fast Fourier Transform* (FFT) is an algorithm able to compute the *Discrete Fourier Transform* (DFT) of a signal in near real-time, making it a widely used and relied upon an algorithm.

The frequency data returned by an FFT can be visualized as a *spectrogram*. Digital *spectrograms* are visual representations of the *spectrum* of signals sampled in the frequency domain. Such *spectrograms* depict the magnitude of an input signal within the full frequency range (spectrum) of an instrument. Spectrograms help evaluate a source signal by visualizing the frequency and amplitude patterns of a sampled signal, including the signal's *harmonics*. Spectrograms can be generated from live sound signals, from the recorded signals of instruments, or from signals generated by sound analysis or synthesis applications, and so on, and are used in light, image, and video processing, in many fields such as physics, chemistry, and the geologic sciences.

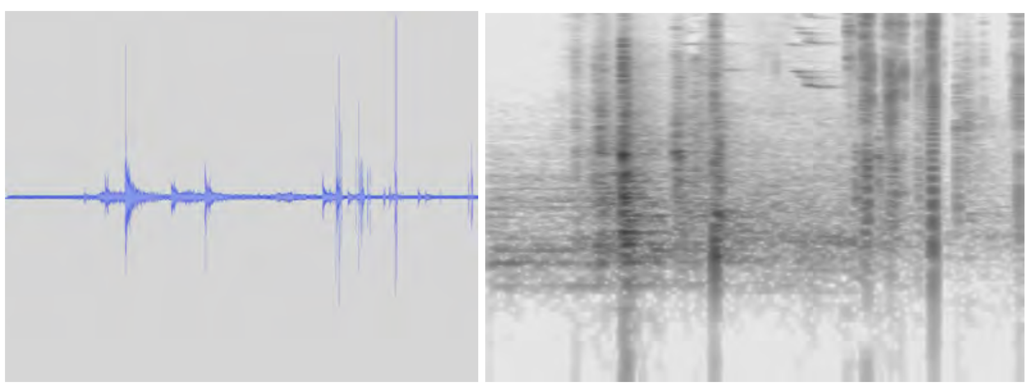


Figure 45: Waveform and spectrum of the same sound sample

A fundamental component of archimusical works is that of sharing modalities and processes between architecture and music. The shared modalities include compositional practices and are explored using computational approaches. One important compositional element that has been examined in this research is that of drawing and graphic notation.

In the essay *Drawing Electroacoustic Music* by Thiebaut, Healey, and Kinns, the role of drawing within computational programs is discussed, and six examples are outlined including the *UPIC, IanniX, MetaSynth, AudioSculpt, Sonos, and Hyperscore*. Each program offers a different perspective on the computational compositional process, creating a foundation for a set of different types of computational compositional approaches (Thiebaut J., 2008). Each program is designed to compose and generate different and specific kinds of sounds, music, forms, and structures.

There are many other software systems not listed in Thiebaut, Healey, and Kinns' essay such as *MaxMsp, VVVV, Grasshopper,* and *TouchDesigner* that offer additional features for the composition of interdisciplinary multimedia artworks and interactive systems including real-time audio-video content and motion graphics, projection mapping, sound synthesis, and connecting to external interfaces.

These programs represent the increased use of creative coding platforms for connecting many different types of media and networking systems to form synthetic ecologies. Each of these programs is successful in certain capacities and can be used for specific purposes. Some of the programs apply mapping that is too limited and/or that results in outcomes that are too narrowly regulated or are over constrained, while others attempt to do too much and become “one-stop-shops,” not strong enough in any particular area (Thiebaut J., 2008). We will avoid the limitations of the *one-stop-shop* approach while continuing to stress the benefits of multimodality as we move into the methodology and contributions sections of this research and describe our effort to develop a computational system with an inherently elastic nature of a mental idea that exists “outside-time” and “outside-space” (Xenakis I., 1992), as Xenakis has put it.

2.5 Archimusic and Iannis Xenakis

Iannis Xenakis was a composer, architect, and, as stated in the title of Sharon Kanach and Cary Lovelace's book, a “visionary” (Kanach, 2010). It is the assertion of this dissertation that, in retrospect, Xenakis, can be considered the single most influential person in the field of *archimusic*. His contributions and insights created radical and inspiring new kinds of musical and architectural compositions and created the first of what is now known as the field of multimedia and interactive installation. Xenakis was a commanding presence in avant-garde architecture and music. He used materials of both architecture and music as one medium. Though these two fields share an age-old relationship, it could be said that architecture and music were never as close as when Xenakis fused them in thought and practice, generating a new form of architecture and a new form of music.

In the past few sections, we have mentioned Iannis Xenakis and many examples of his work regarding the topics of notation, instrumentation, spatial sound, and sonic spaces. This section will delve into Xenakis’ most significant contributions, archimusic works that, in the view of this research, are the canon of archimusic. These include a progression of trans-disciplinary thinking and making that began utilizing translational methods and advanced into creating the first transformational methods. In the following section, we first discuss selected archimusical works of Iannis Xenakis, followed by examining his archimusical processes, including his concept of a general morphology and transfers.

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2.51 Archimusical Works of Iannis Xenakis

The contributions of Xenakis are prevalent in the arts and sciences of both architecture and music. Though Xenakis saw the "field of architecture as a science and the field of music as the most abstract of the arts" (Sterken, 2007), he was able to push each field forward by using his findings in the other. None of this would have been possible without his keen interest in mathematics, physics, and astronomy as well as formulating his thoughts and ideas using drawing.

Xenakis worked for Le Corbusier for 12 years and over time was able to build the confidence of his employer until he was given a project of his own. This was the Philips Pavilion for the 1958 World's Fair in Brussels that was inspired by his 1954 piece Metastaseis, transforming the instrumental glissandi into an architectonic structure. After leaving Le Corbusier's office, Xenakis would concentrate on music, though his relationship with architecture would continue. Xenakis went on to write pieces such as, *Terretektorh* (1965), *Nomos Gamma (*1967), *Persephassa* (1969), which along with the previous *Pithoprakta (1955)* collectively dealt with spatial constructs and physical diffusion. Finally, he was able to bring both these fields together in a most extraordinary way, creating spatiotemporal hybrids known as the *Polytopes*.

The Polytopes were audiovisual installations that used sound and light in various capacities to build a spectacle: music to be seen, architecture to be heard. Xenakis dealt with abstract concepts and the intuitive human nature of abolishing rules in order to create new ones that connected the arts of architecture and music in novel ways.

2.411 Sainte Marie de La Tourette – Modular (1954)

La Sacrifice was one of Xenakis first musical works composed in 1953. The Fibonacci series was used as a fundamental component to the composition. He integrated eight numbers of the Fibonacci series into eight pitches of eight durations. The *Modula*r became a principle design concept in much of Corbusier's work and when Xenakis was given his first project, the Façade of the *Secretariat* building in Chandigarh India he used it to help develop the proportions of the façade's glass planes. This same method of the Modular went on to be used in Le Corbusier's *Convent de la Tourette*, located outside of Leon France where Xenakis was again charged with designing the building's west facade. Using these same proportions, Xenakis was able to compose the famous *pan de verre ondulatoire* (undulatory glass planes), rhythms of light made through the composition of the windows and mullions that ran down the hallway creating visual melodies and vertical polyphony in triple layered arrangement (Sterken, 2007). The *Convent de la Tourette* facade was designed in both the X and Y dimension, whereas the *Secretariat* building used only the vertical dimension.

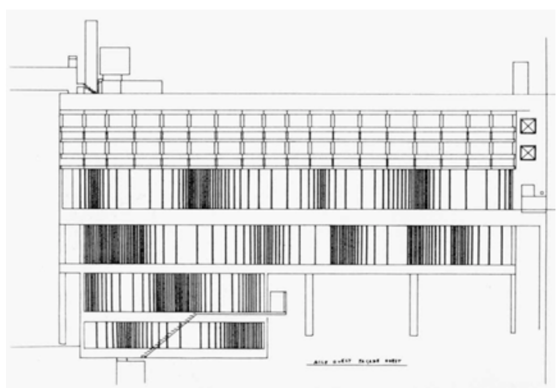

Figure 46: Sainte Marie de La Tourette (1954). Image: fondationlecorbusier.fr

2.412 The Philips Pavilion – Metastaseis (1958)

After building the confidence of Le Corbusier, Xenakis was entrusted to develop Corbusier's commission to design and build a Pavilion for the Dutch Philips Corporation for the 1958 World's Fair in Brussels. Corbusier told the Dutch Philips Corporation that rather than build them a pavilion; he would give them a *Poème électronique* (Woodstra, 2005). The commissioned included Edgar Varese who composed a work (*Poème électronique*) to be played within the pavilion, showcasing the technology of the Philips Corporation.

Xenakis previously completed the musical piece *Metastaseis* that is known for having the notational glissandi (bars 309-314) weaving up through the score. The *Philips Pavilion* would be become a continuation of this 1954 piece by transforming these instrumental glissandi from musical graphic notation into the architectonic structures of ruled surfaces that became the hyperbolic parabolas of the pavilion's form. The *Philips Pavilion* was also one of the first hyperbolic architectural structures ever built.

Hundreds of loudspeakers were arranged throughout the flowing interior space using a probability formula in which Xenakis was becoming increasingly interested. Xenakis had begun to experiment with the concept of probability in both architectural and musical forms, which was to become known as *stochastic music*. These speakers spatialized the sounds of Varese's composition along with a composition by Xenakis called *Concret PH. Concret PH* consisted of recordings of burning cinders, meant to cleanse the visitor upon arrival and exit. Accompanying the compositions of Varese and Xenakis were a series of images curated by Le Corbusier. Projected on the interior walls, these images denoted Le Corbusier perspective of culture, technology, and a view of the future.

The project was a success, and though it has inspired many structures since its creation, none quite like it either in physical form or in the methods with which it was programmed, has ever been built. This Pavilion gave Xenakis the opportunity to focus on his craft – drawings, composing space and transforming space through sound. Along with the ideas explored in the *Philips Pavilion*, he continued to inform the principles that developed in his music and throughout his career, searching for the finite connections between music and architecture. The Philips Pavilion is, without a doubt, one of the most influential works of archimusic and presents the foundation of the transformational integrations of archimusic that this research is concerned with advancing.

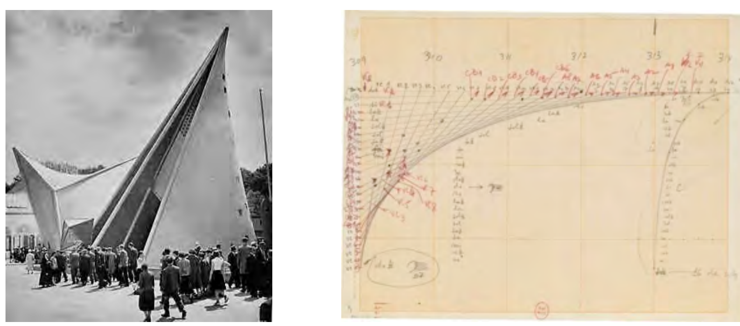

Figure 47: Philips Pavilion by Le Corbusier & Xenakis, Metastaseis by Xenakis. Image: fondationlecorbusier.fr & http://iannis-xenakis.org/

2.413 Le Corbusier

Xenakis criticized aspects of Le Corbusier's contribution to the *Philips Pavilion*, including his selection of visual projections, stating that they were too literal. In fact, there were many differences between Xenakis and Le Corbusier and these would ultimately lead to his termination at Le Corbusier's Office. Elizabeth Sikiardi discusses some of the similarities and differences between Iannis Xenakis and Le Corbusier regarding the formation of their distinct styles and processes in her text *Morphologies*. Though their shared history ended poorly, (the locks to Corbusier's studio were changed while Xenakis was on leave, in what was become known as the Xenakis incident) (Hewett, 2010) the amount of experience that Xenakis gained during this time went on to affect both his architectural and musical work.

Sound, mathematics, and philosophical thought are some of the distinctions between Le Corbusier and Xenakis. Xenakis was trained as a civil engineer and had a profound interest and a deep understanding of mathematics and the sciences; this differed significantly to Le Corbusier's relationship to mathematics. Corbusier was said to have written a note to a mathematician that "he was an ass when it came to the ways of mathematics" and that "he was merely an architect looking for the means to incorporate the mathematical arts into his designs" (Sikiardi, 2007).

Another distinction was based on a similarity, each having a passion outside of architecture. For Xenakis is was music, and he would compose in the evenings after finishing his work for Corbusier's office. Le Corbusier, on the other hand, was a sculptor and painter and was known to spend his morning's painting and sculpting before to coming into the office to practice architecture. The objective difference here is this: Le

Corbusier practiced making opaque and static forms in space, while Xenakis' composed transparent and dynamic forms that unfolded with time.

The most obvious distinction is their geometric styles. Le Corbusier's geometry was rectilinear, while the forms of Xenakis were fluid and parabolic. This difference seen in the design for the *Philips Pavilion*. Le Corbusier championed the *plan* as the purest form of architecture (Corbusier, 2007) and concentrated heavily on plans and sectional diagrams in his seminal texts the *Modular 1 and 2* (Corbusier, The Modulor and Modulor 2, 2004) that outlined the proportional system based on a 6' tall man and the golden ratio. Xenakis, on the other hand, argued for a truly volumetric architecture (Hewett, 2010) and that architecture in plan and section was still only two-dimensional, having the third dimension extruded up from the two-dimensional plan. Xenakis began working with hyperbolic parabola as a potential answer to this problem, and this shape became one of his signature forms. Another contrasting component is Le Corbusier's proportional system of modular and Xenakis' use and exploration of stochastic methods and probability theory as a compositional system.

After leaving Le Corbusier's office in 1959, he would primarily concentrate on music, though his relationship with architecture was not finished and would later build to a climax of synergetic exploration. His musical compositions would integrate spatial components and those spatial components would influence the new directions for music, transforming his methods for generating new spatial works. The previously mentioned works *Metastaseis* and *Le Sacrifice* dealt with proportions found in *Fibonacci*, the golden section, and were partially informed by the Corbusier's *Modulor*, but as time progressed these ideas evolved and resulted in building spatial and temporal structures with entirely new proportional developments. Xenakis wrote pieces such as *Terretektorh* and *Nomos Gamma*, which along with *Persephassa* would all deal with spatial constructs and physical diffusion. By placing the orchestra throughout the audience (as in *Terretektorh*) the method of distribution was similar to the loudspeaker placement in the *Philips Pavilion*. The location of each audience member had a different proximity to various sound sources and thus would have a unique experience of the same composition. Spatializing sound was accomplished using different methods, as seen in *Persephassa*. In *Persephassa* six percussionists were placed in a hexagonal shape as they played together, the sounds would shift in space. These ideas of a musical space would be combined with Xenakis' *stochastic* concepts to diffuse the spatial components and bring concepts of *Brownian motion* and space-time into the compositional process.

2.414 The Polytopes

Throughout the late 1960's and 1970's, Xenakis was able to bring the fields of architecture and music together in a most extraordinary way. He called these new hybrids the *Polytopes*. The Polytopes are immersive audiovisual installations that used sound and light in various capacity to build a spectacle, *music to be seen, architecture to be heard.* The *Polytopes* are perhaps the best examples of Xenakis' use of space as a compositional material. These *audiovisual spectacles* (Harley M. A., 1998) created one composition for the ears and another composition for the eyes, forming the precursor to the light, sound and interactive and immersive installations that are commonly seen today.

The first of these Polytopes was the *Polytope de Montreal*, built in a 4-story high atrium for the *Ottawa Art Gallery* opening at the World Expo in 1967. Here the same drawing of glissandi from of Metastaseis can be seen suspended in space creating a dynamic sculpture. Twelve hundred strobe lights, capable of programmatic control, were attached to stainless steel cables which stretched across the atrium creating a ruled surface similar to the Philips Pavilion. Four sets of loudspeakers were placed throughout the atrium one set per floor. The eight-minute audiovisual composition was played flashing and sounding with continuous stochastic patterns once every hour.

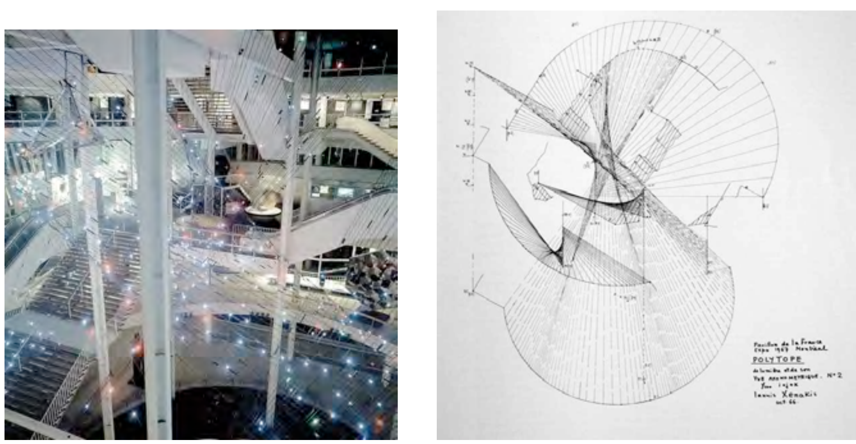

Figure 48: Polytope de Montreal by Iannis Xenakis (1967). Image: http://iannis-xenakis.org/

The *Polytope Persepolis* was the second Polytope. Performed in the fall of 1971 at the ancient ruins of the Temple of Darius in Persepolis, Iran, this Polytope broke free from the confines of conventional walls. The unique evening performance took place outside in a natural environment, and incorporated sirens, searchlights, bonfires, lasers, 150 children holding torches and eight loudspeakers (one for each channel of the composition) located at six different areas throughout the temple site. Xenakis stated, “Persepolis is neither a theatrical spectacle, nor a ballet, nor a happening. It is visual symbolism, parallel to and dominated by sound. The sound—the music— must absolutely prevail” (I. Xenakis, Persepolis, 1971).

Figure 49: Polytope Persepolis by Iannis Xenakis (1971). Image: http://iannis-xenakis.org/ & Iannis Xenakis Archives, Bibliothèque Nationale de France

Persepolis was recreated at the Historic State Park in Los Angeles in 2010 for the Drawings Center and MOCA Los Angeles exhibition of the works of Xenakis curated by Sharon Kanach and Casey Lovelace. The re-creation was not located within the vacant memories of an ancient place, but rather in a park outside the dense urban metropolis of

Downtown Los Angeles, providing an interesting shift that felt transplanted in a city of the future. The work was curated by Kanach with Lovelace serving as the Creative Director alongside Daniel Teige with Embrace the Void Design. I had the fortune of witnessing the event first hand and felt a sense of wonder instilled of what the original must have been like amongst ancient ruins, echoing voices and stories of an ancient culture and tradition.

Figure 50: Persepolis 2010 Los Angeles recreation by MOCA (2010).

The *Polytope de Cluny* was installed at the Cluny thermal baths in Paris' fifth arrondissement in the fall of 1972. In the *Polytope de Cluny*, a computer system was used to control a composition of hundreds of strobes suspended in an isosurface formation as well as a system of lasers and adjustable mirrors that created geometries of light unfolding across the scaffold interior of the ancient baths. A seven-channel, twenty-four-minute composition was composed of electroacoustic and computer-generated music and spatialized throughout the space. The audience lay on floor pillows and cushions watching the light and laser show overhead enveloped in spatialized sound. The audience was a necessary factor in all of the Polytopes; they were moving, lying diffused amidst the work. They were, in fact part, of the work and considered part of the composition.

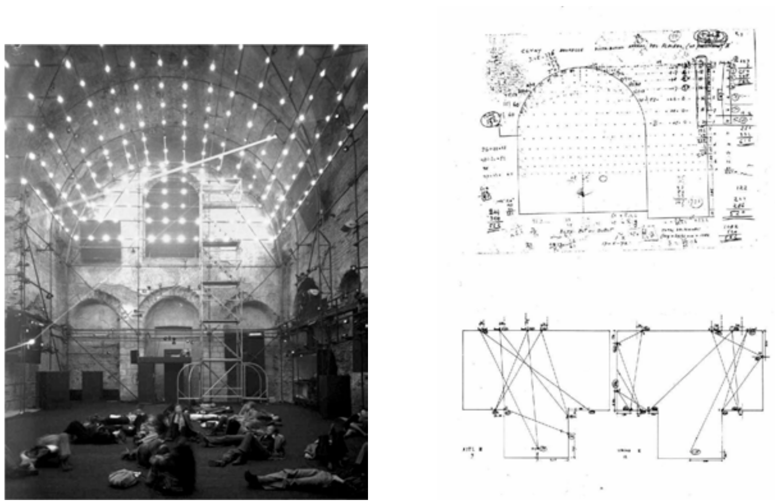

Figure 51: Polytope de Cluny by Iannis Xenakis (1972). Image: http://iannis-xenakis.org/

The *Polytope de Mycènes* was exhibited in the ancient temple site in Mycenae Greece in 1978. This was the first time Xenakis had been back to his home country since fleeing, during the occupation of Greece in World War II. Like Persepolis, *Polytope de Mycènes* was a synergy of electro-acoustic music, theatrical agents, ancient architecture and open-air environments, a kind of sonic earthwork where children with torches, bonfires, herds of livestock with lights strapped to their sides, and fireworks accompanied video projections and readings of Homer filled the ancient landscape. The musical component to this spectacle was the composition *Mycènes Alpha*, which was one of the first compositions that used Xenakis' computational compositional tool known as the *UPIC*, which will be discussed later in this section. The number of different in this Polytope addresses the very nature of order and complexity, forming a choreographed, dynamic event composed of life itself.

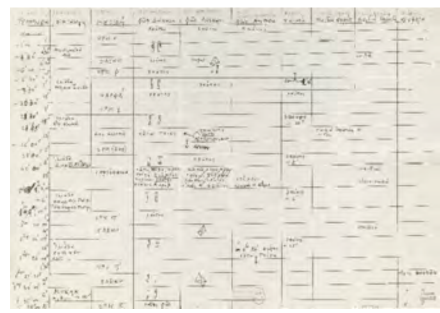

Figure 52: Polytope de Mycènes by Iannis Xenakis (1978). Image: http://iannis-xenakis.org/

2.415 The Diatope – The Legend d'Eer (1978)

The conclusion of the Polytopes transitions into one of Xenakis' strongest works, the *Diatope*. The *Diatope* along with the Philips Pavilion from 20 years earlier, bookends the Polytope explorations by transitioning back into the architectonic sphere. Commissioned for the opening of the Centre de Pompidou in 1978, the *Diatope* had formal and tectonic similarities to the Philips Pavilion. Inside a thin red vinyl surface stretched across a steel truss structure was "a matrix of 1,680 flashbulbs, four lasers, and

400 positionable mirrors that were programmed with the 7-channel electro-acoustic and computer composition *La Légende d'Eer*" (Harley M. A., 1998), which was originally inspired by Plato's *Republic*. The Diatope was the epitome of Xenakis' abstracted form, reducing the structure to a thin membrane where even the temperature outside could now be felt within the space (Xenakis I. a., 2008), evolving his immaterial aspirations for a truly "*volumetric architecture"*.

The same malleable material that created these archimusical works is found in the argument of the *Diatope*. The argument defined a geometric and philosophical question for the ages (Xenakis I., 2008) and demonstrated the relationship of geometry and philosophy. The Diatope contained an argument composed of a pentagon with five vertices, one for each philosophical argument: *La Légende d'Eer* from Plato's *Republic* (vertex one), *Poimandres* by Hermes Trismegistus (two), *The Infinite* by Blaise Pascal (three), *Siebenkäs* by Jean-Paul Richter (four) and *Supernovas* by Robert Kincher (five). This manner of crystallizing thought in mathematics and philosophy aims at understanding the realm of the intellect. The *Polytopes* were the pinnacle of Xenakis' ability to form a spatiotemporal typology that synthesized both music and architecture, each raising the other to a higher capacity.

Figure 53: The Diatope by Iannis Xenakis (1978). Image: http://iannis-xenakis.org/

2.416 UPIC (1978)

Beginning around 1953 Xenakis began developing a compositional method and tool that would translate drawings into sounds. In 1978, twenty-five years later while at the CEMAMu, the first version of the *UPIC* (*Unite Polygogique Informatique de CEMAMu*) was employed to compose two works, that were used in the previously mentioned Polytopes: The *Mycenae Alpha*, the sonic component to the Polytope de Mycenae and *La Légende d'Eer*, the sonic element to the *Diatope*. The *UPIC* was an early example of a musical compositional tool developed by Iannis Xenakis in 1978. It consisted of a digitizing tablet and an electrostatic pen that were used to draw the waveforms of sound. This tablet and pen were attached to a computer that would synthesize the hand-drawn waveforms into sound. Arcs were drawn and operated upon to create unique timbres and compositions. Over the following decades, different hardware and software versions of the UPIC would go on to influence other programs.

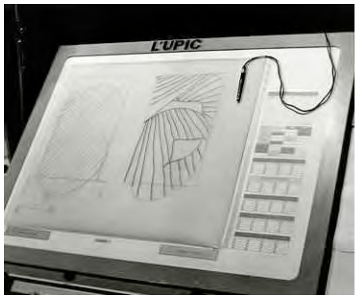

Figure: UPIC by Iannis Xenakis (1978). Image: http://iannis-xenakis.org/

The *UPIC* was inspired by the drafting table and graph paper as pointed out by Sharon Kanach (Hewett, 2010) and allowed for waveforms and envelopes to be drawn on one of four pages that can be loaded at a time. The direction, speed, and tempo of the playback were programmed, and the system enabled the copying, editing, and saving of sequences for later playback. The markings made on the UPIC are known as *arcs,* and each page contained between 1 and 4000. Each arc has an associated oscillator, which could be modified with certain attributes such as waveforms, envelope, frequency table, amplitude table, weight, modulating arc, as well as operators such as rotation, symmetry, and alignment. The synthesized sound could be played out of any of the 16-channels. Not only did Xenakis contribute to the fields of music and architecture he developed a system by which to transform ideas from one field into the other. Many well-known composers used different versions of the *UPIC* including Francois-Bernard Mache, Curtis Roads, Karlheinz Stockhausen, and Jean-Claude Risset.

2.417 Cite de la Musique (1984)

The *Cité de la Musique* started as a design competition (1983-84) for the new National Music Conservatory, to be built at the Parc de la Villette in Paris. Xenakis collaborated with Jean-Louis Véret and submitted a design for a “new type of architecture more flexible and dynamic for all types of present day music" (Xenakis I. , Music and architecture: architectural projects, texts, and realizations, 2008). The design had a capacity for 1200 people and a potato-shaped floor plan with a spiral gallery running around the inside of the walls which "can accommodate the audience and also musicians, so as to produce a three-dimensional soundscape” (Glissant, 1986). Within a vaulting hyperbolic roof, the floor was designed to raise and lower to accommodate a wide variety of staging configurations. In the end, the Xenakis and Véret made it to the final round of the competition, but lost to the architect and now Pritzker Prize winner Christian de Portzamparc. Had this project been realized, it might have been Xenakis' crowning architectural achievement and paved the way for a new type of concert hall that exemplifies the *future building for music* (Forsyth, 1985).

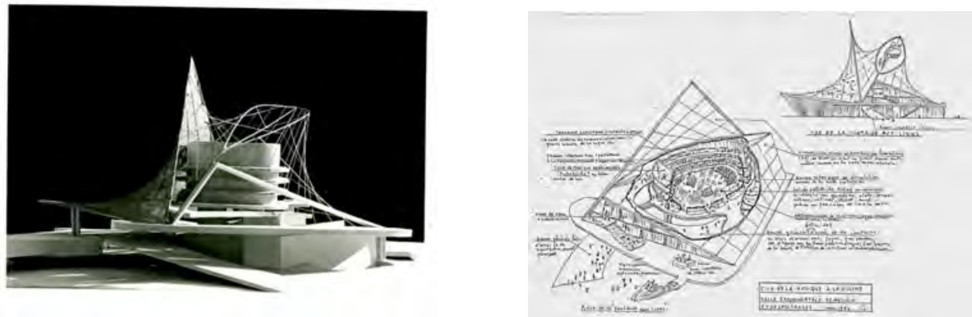

Figure 54: Cite de la Musique (1984). Image: http://iannis-xenakis.org

2.418 Additional Projects

Xenakis continued to practice architecture and work as an engineer on architectural projects. Xenakis designed homes including the *Reynolds House*, *Villa Mache,* and a conceptual music studio for the conductor Hermann Scherchen. The *Reynolds House* was designed for the conductor, friend and supporter, Roger Reynolds and his wife, Karen, while the *Villa Mache* was created for his daughter and her husband, the composer Francois Mache. Xenakis also built a summer residence, on the island of Corsica where he and his family spent their summers. His daughter, Makhi, describes this home as, "*the place where he would renew himself every summer, along with my mother and me. Corsica replaced Greece, where from 1947 to 1974 he was not permitted to travel because of his former political activities. In Corsica, he could calm his fears and shed his anxiety for a month and confront the wildest aspects of nature that he could find*" (Xenakis M., 2010). Continuing, she describes what an embodiment of Xenakis' flowing nature: "*Sitting cross-legged, he would pore over a book of Plato or mathematics. He sometimes stared at the sky, searching for that particular moment when he could at last, in extreme hand-to-hand combat, draw close to the untamed elements of nature, to nourish and renew himself in them. He's standing there now, facing the raging sea, his face radiant, peaceful at last, reflecting a particular serenity that signifies that this moment won't escape him any longer"* (Xenakis M., 2010).

Xenakis developed the theoretical project *Cosmic City* for the city of Paris as a study of what the city of the future might look like. Many well know architects including Le Corbusier participated in this theoretical competition. Xenakis' design was inspired by the heavens and the structure of the cosmos, creating a living constellation that was to be inhabited by a future society of five million in his "5000-meter-high hyperbolic parabolic envelopes" (iannis-xenakis.org).

Figure 55: Cosmic City by Iannis Xenakis (1965). Image: Iannis Xenakis Archives, Bibliothèque Nationale de France, Paris

2.52 Archimusical Processes

Surveys of Xenakis' works are well documented, providing considerable insight into the understanding of his creative processes and developments in the field of archimusic. Examples can be seen in Sven Sterken's essay "*The music of space and towards a space-time art*", which concentrates on the Polytopes, and Joseph Clarks' critical essay "*Iannis Xenakis and the Philips Pavilion*" that provides facts surrounding the Xenakis incident.

Sharon Kanach has been the leading authority on the life and work of Iannis Xenakis Her contributions are far-reaching, and her efforts have led to the publishing of numerous books focusing on the different aspects of Xenakis' work. *Iannis Xenakis: Composer, Architect, Visionary,* edited by Carey Lovelace, focuses on the nature and use of drawing in Xenakis' works. The book *Music and Architecture* by Xenakis and Kanach discusses the architectural texts and projects of Xenakis, including his time with Le Corbusier, the *Polytopes*, the *Diatope*, and other architectural works. *Performing Xenakis* is a collection of essays by the many composers that have worked with Xenakis, discussing their experiences and their overlaps. *Xenakis Matters: Contexts, Processes, Applications* is another collection of essays from architects, composers, and artists focusing on the realm that Xenakis pioneered and illustrating how it is still a place for continued exploration. Xenakis' book *Arts/Sciences: Alloys (Aesthetics in Music)* is a text outlining his interdisciplinary approach toward the artistic and scientific construction of compositional works that are synergies of mathematical, philosophical and computational thinking and making. Andrew Lucia and Jenny Sabin describe Xenakis' *book of screens* in their essay "*Rethinking Xenakis*", while Philipp Oswalt and Elizabeth Sikiaridi describe Xenakis' methods of spatial composition and the transfers of modes in their essays "*Densities*" and "*Methodologies*" respectively.

We can cultivate a great deal of information by analyzing Xenakis' repertoire in the architectural and musical realms, and each of these studies and perspectives offer increased resolution to the archimusical contributions we are developing in this research. In this section, we describe the creative processes of Iannis Xenakis:

2.421 General Morphology & Transfer of Modes

Iannis Xenakis had a commanding presence in the avant-garde fields of both architecture and music. By using the materials of both music and architecture as a single medium, Xenakis introduced novel ways to compose within the trans-disciplinary spatial and musical realms of the field now referred to as archimusic. Though these two fields share an age-old relationship, as we have discussed throughout the background chapter of this research, it could be said that architecture and music were never as close as when Xenakis fused them in thought and practice, and in doing so generated a new form of architecture and music. Xenakis accomplished these new modalities through his use of transformative methods known as *general morphology*, and *transfers* (also known as the *transfer of modes*).

As we begin, a few notes on the development of Xenakis' perspective will be helpful to understand the context of these transformational methods better. Xenakis was influenced by two people persons in the development of his unique perspective. Both Olivier Messiaen and Le Corbusier had a large influence in his life, although in different capacities. The composer Olivier Messiaen was a mentor to Xenakis and greatly encouraged his musical thinking, having at one point given him the advice to seek inspiration in his training as an architect, study of mathematics as well as his fortune of being a Greek (Lovelace, 2010). Le Corbusier would be an influence throughout the twelve years that Xenakis worked for him, contributing to the act of drawing, spatial development, and ordering known as the *Modular.* These contributing mentors shaped his development and enabled Xenakis to work seamlessly between the different disciplines, advocating the continuation of these working and thinking methods in the arts and sciences.

Xenakis' *General Morphology* is akin to Richard Wagner's *Gesamtkunstwerk* and Le Corbusier's *Synthesis des Arts* (Von Moos, 2009). Each of these relates to the idea of a *total work of art* across the disciplines of space, light, sound, architecture, and music. A total work of art is a work that is cosmic in scale, and focuses on the human senses and philosophical concepts, creating new ways to relate ourselves to a higher order and the environment. Xenakis' *transfers* is an important and robust concept focused on exploring the transferring of content from one modality to another by applying the same mental structures to both fields (Sikiardi, 2007). The concept was utilized in the construction of many works including the *Philips Pavilion, the Polytopes, Diatope, Sieves Theory*, along with his *stochastic* methods.

These multimodal assemblages, employing his concept of transfers toward a general morphology, ultimately created Xenakis' concept of *alloys*. This concept would generate and organize the mass of clouds of sounds and galaxies of light of the Polytopes, and create a matrix of ideas, actions of energy and mental processes. Thus, becoming a state of crystallization that echoed the following statement of Xenakis: Music must be a crystallization, a materialization of this intelligence (Sikiardi, 2007).

Sven Sterken writes about this relationship in his essay "*Music as an art of space: Interactions between music and architecture*" by delineating the two spheres of thinking used. The first, Sterken calls the *intellectual*, and the second, the *phenomenological*. The *intellectual* is concerned with how ideas and concepts can be translated between the two arts. The *phenomenological,* on the other hand, is concerned with the expressiveness of space and how space can be used as a compositional parameter. The text outlines these two spheres and establishes an additional frame through which we understand Xenakis' working relationships and processes.

Xenakis' transfers can be seen translating modalities and disciplines to explore the different capacities of a musical or architectural form. Metastasis exemplified transfers, especially in the sonic realm. It utilized and incorporated elements of the

Fibonacci series in its first and second parts respectively. This work is perhaps the most well-known for its graphic use of the discussed glissandi seen in the graphic score. Here, we can follow the process into the material realm, as the glissandi lines become the ruled surfaces of the thin concrete shells of the Philips Pavilion.

Xenakis uses space to modulate and forever change the way a listener *hears* music, and in the end, *sees* space through its active role in the compositional process. Together, the intellectual and phenomenological establish a frame to understand Xenakis' working process of relating the disciplines of architecture and music in different capacities.

2.422 Qualitative and Quantitative

The spaces of architecture and music exist in different spatial capacities. Through abstract methods, we can categorize them as *material* and *energetic* spaces. Philipp Oswalt and Sven Sterken outlined similar concepts in their essays "*Architecture of densities*" and "*Towards a space-time art*" respectively. They focused on the ideas related to the work of Xenakis and his effect on the development of multimodal spaces.

Material space is concerned with spatial structures, material organization, and static, quantitative, and physical differentiation, while *energetic space* is interested in the sensory spaces of the qualitative and dynamic. Each of these spaces is used as parts to compose a whole space. This is to say that a complete or whole space consists of the static and dynamic, the quantitative and qualitative, and the material and immaterial. The poetic and synergetic combination of these two types of spaces is what can create a whole and complete space.

Material space is usually the static and homogeneous space seen in physical structures and material characteristics. These spaces enclose the *energetic space*, and the energetic spaces, in turn, give life to the material space. They are Euclidian in nature, being designed, notated, and drawn in the conventional three spatial dimensions and do not normally transform over time.

Energetic space is considered the dynamic and heterogeneous space, and is always evolving and changing. Energetic space can be defined by a dynamic field such as an electromagnetic field in the form of a Wi-Fi or internet signal that strengthens or dissipates depending on location. A campfire on a cold night is another example of an energetic space that can be sensed by our bodies; the closer to the fire your body is, the warmer you feel, but as you walk away from the fire, you begin to feel the cold (Oswalt, 2001). These energetic spaces are closely related to light and sound spaces. As the light and/or sound are projected, it defines a space differentiated from the surrounding material.

Material and energetic spaces are not unique to a single discipline (architecture or music). The material may appear to relate more to the architectural, while the energetic may seem to relate more to the musical, but these spaces have more impact if related to the context of both disciplines simultaneously. Therefore, the spaces of archimusic aim to utilize both.

The material and energetic spaces in Xenakis' methodology can be seen outlined in the chapter *Concerning time, space and music* of his seminal text *Formalized Music.* Here, Xenakis described how music is to be related to the scientific and philosophical concepts of time and space. Xenakis introduced statics and probability theory into music, contending with the novel questions of his day. Xenakis believed that music imparts insightful comprehension and the purest understanding of both humanity and the universe. He composed using mathematics and physics, because, in his opinion, these are inherent to the philosophical relationships of understanding and intuition. Xenakis' Greek identity had influenced his notion of the intuitive, philosophical, and scientific. He used ancient Greek concepts to illustrate this interconnectedness.

2.423 Sound Space and Graphic Composition

Xenakis' interests included mathematics, physics, and astronomy, and through his studies at the Polytechnic in Athens, he began drawing on *graph paper*. Throughout his work as an architect and his formal musical scores, one staple that flows through all is the use of drawing and graph paper (Kanach, 2010). Xenakis' ability to draw, and use of graph paper to abstract the literal graphic nature of the compositional processes of both art forms enabled him to write music as he drew architecture, and draw architecture as if he wrote music. Abstracting the content in this manner allowed Xenakis to merge musical compositions and spatial experiences. He was able to see the drawing in different modalities, whose forms were continually transforming and evolving freely between the two fields.

Sharon Kanach and the Drawings Center's exhibition at the MOCA Pacific Design Center, in Los Angeles in 2010, stated: Drawing was central to Xenakis' working method as a designer of sound and space, and the meticulously hand-rendered scores and graphic studies, both architectural and musical…express a spatial understanding of the page as much as they do a palpable sonic quality. These innovative drawings reveal a radical visualization of sound and give insight into this extraordinary innovator's process of 'thinking through the hand.' The musical documents…are evidence of one of Xenakis' signature innovations, which was to integrate advanced contemporary mathematics as a compositional tool (Kanach, 2010).

In many of Xenakis' musical works, he began by drawing or sketching the composition. As Kanach outlines in her essay "*Music to be seen: Tracing Xenakis' creative process*": In the same manner that a blueprint enables the eye to capture the layout of any surface at a glance, Xenakis' graphic renderings of a musical work allowed him to judge its global form in an instant, using a similar, plastic and aesthetic approach (Kanach, 2010). His use of graph paper would break the formal traits of the traditional five-line staff notation and encouraged the exploration of the pitch, amplitude, duration, and density outside of conventional exploration. From the mental structures that exist in what Xenakis called *outside-time,* the thoughts and forms allowed a fluid movement within the *temporal flux* of the compositional process.

The gridded paper used for engineering served to abstract the notion of the *twelve notes* of tonal music, and led him to explore the in-between spaces as seen in the previously mentioned glissandi diagrams of *Metastasis*. These become the concrete volumes of the parabolic parabolas of the *Philips Pavilion*, and the curved string surfaces of the *Polytope de Montreal* suspended within the French Pavilion. The forms of sonic events that traced lines through the audience of *Terretektorh* became the traveling torches of the *Polytope de Mycenae*, and the intricate sonic shapes represented in the 400-loudspeaker array of *Hibiki Hana Ma*. They also become apparent as the laser lines of the *Polytope de Cluny* and the *Diatope*.

The spaces in which Xenakis' music was composed dealt with equally diverse ideas. The Polytope pieces of *Persepolis* and *Mycenae* were performed not in a concert hall or amphitheater, but outside, at the ancient sites of Temple of Darius (*Persepolis*) and the temple of Mycenae (*Polytope de Mycenae*). They were treated as a multimodal development of sound, space, architecture, and culture. Xenakis employed locals to produce the instruments, including the making of bells for the performing livestock in Mycenae, the torch-bearing children (one-hundred-fifty of them in the *Polytope of Persepolis*), and the utilization of military searchlights provided by the Greek Ministry of

Defense. Developing not only the methods, but also the context was his principle interest. This was to become the fabric in which he was able to bridge architecture and music.

In the composition *Terretektorh*, Xenakis created paths of sound that weave through space. This was achieved by spacing the orchestra throughout the audience, allowing a tone or sonic event to travel from one space to another, either in front, in the back, or straight through the audience space. This concept was also explored in the compositions *Nomos Gamma* and *Persephassa*. The percussion component of the orchestra was arranged as a geometrical primitive surrounding the audience. *Nomos gamma* used an octagon, while *Persephassa* used a hexagon. Outside of Xenakis' orchestral compositions, *Hibiki Hana Ma* can be seen as an extraordinary example of electroacoustic music that uses space as a compositional parameter. Composed for the 1970 World Expo in Osaka, Japan, this work was performed in the Federation Steel Pavilion, and used 400 loudspeakers to create complex sonic geometries in space where no one person would have the same experience.

Xenakis' methods of graphic notation and composition helped in demonstrating his concept of *transfers*. His musical compositions exist in both graphic and notational forms. Some composers were satisfied with having their compositions being interpreted by the musician or instrumentalist. Xenakis, as Kanach states, always finalized the score in the traditional form, which notated 'what must be played' (Kanach, 2010). The graphic scores of many of Xenakis' works experimented with the generation of the compositional form, as seen in *Pithoprakta*, or certain timbral or tonal elements of *Mycenae Alpha*, while others explored the spatial layout of the orchestra and loudspeakers as described in *Nomos Gamma* and *Persepolis*. Xenakis' graphic notation is also linked to the personal growth of his computational compositional tool known as *UPIC*. His involvement with the compositional process of architecture and music, and his ability to draw and use of graph paper allowed a fluid translation between these two modalities. Many of these graphic notations can be imagined as spaces to be inhabited. They also allowed the linear temporal nature of the musical form to be taken in and understood in its entirety (Kanach, 2010). The age-old arts of architecture and music were joined in new and extraordinary ways with the works of Xenakis, and this research aims to continue this exploration.

Xenakis' contributions connected the fields of architecture and music by contending with abstract concepts, mathematical and spatial constructs, and intuitive human nature to abolish old rules and create novel methods. His practice as an architect and engineer served his practice of composing with space and material, and informed his methods of musical composition, leading to new synergies that exist not in one discipline, but in both.

3. Conceptual Framework

"I constantly refer to music in referring to architecture, because to me there is no great difference – when you dig deep enough in the realm of not doing things but simply thinking of what you want to do – that all the various ways of expression come to the fore. To me, when I see a plan, I must see the plan as if it were a symphony, of the realm in spaces in the construction of light."

~ Louis Kahn (Lobell, 1979)

It is essential to acknowledge that contemporary efforts are yet to yield the kind of impact and influence capable of significantly moving the discipline of archimusic forward. Recent works implement methods of association and translation that revisit the distant past rather than pushing the transformative methods of archimusical forward.

The question that naturally arises is this:

How can we advance the transformative and compositional methods of archimusic?

This dissertation, in particular, will contend with the following three problems, which together aim to advance the transformative and compositional methods of archimusic:

1: *How might the information and resources related to the intersection of architecture and music be organized into a learning resource that supports the future dissemination of this research?*

2: *What is a contemporary method for evaluating the trans-disciplinary relationships of archimusical works?*

3: *How might a computational tool be developed to generate new transmodal integrations between the digital forms of architecture and music?*

This dissertation examines these three problems by developing three corresponding contributions:

1: *The Archimusic Repository is a knowledge resource organizing the conducted research into an online repository for the documentation of the field.*

2: *The Archimusical Transmodal Matrix is an evaluative method to analyze and map the translational and transformational processes of multimodal works of archimusic.*

3: *Kosmos is a generative system that integrates new digital modalities into the transformative compositional processes for generating new archimusical works.*

Together these three components aim at contributing to the advancement of the archimusical field, creating a robust understanding of the past developments between these two fields (*Archimusic Repository*), a novel way to investigate current contemporary works (*Archimusical Transmodal Matrix*), and a generative way forward for the future development of archimusic (*Kosmos*).

In the following sections, we will look at the conceptual framework that underlies these three developments. First, we will describe the trans-disciplinary nature of the research and its relationship to the processes of Xenakis. Next, we will introduce the three archimusical contributions, which will be the focus of the next chapter of this research. Lastly, we will present the concept of *Archimusical Synthesis* and the key ideas that have developed out of it. These key ideas include the technique of *space-time composition,* which addresses composing with the dimensions of space and time, *spatiotemporal sampling,* which samples both spatial and sonic elements of a given space, and *allograms,* which enable the digital modalities of architecture and music to be unified.

3.1 Trans-disciplinary Approach

The methodology of this research is multimodal, trans-disciplinary, and encourages new tools, methods, and resources to translate and transform the architectural and musical modalities across their conventional barriers to generate new and compelling archimusical material. After examining the work and creative processes of Xenakis, I found that his trans-disciplinary concepts of *transfers*, *general morphology* and their role in the development of the *UPIC* offer influential direction for the advancement of the field of archimusic. Xenakis' *general morphology* is the concept of a total work of art between the disciplines of architecture and music, akin to Richard Wager's *Gesamtkunstwerk* and Le Corbusier's *Synthesis des Arts*. His concept of *transfers* is a robust method focused on exploring the transferring of content from one modality to another by applying the same mental structures to both the fields. The *UPIC* is a computational musical tool for composing and synthesizing new timbres and musical forms from drawings.

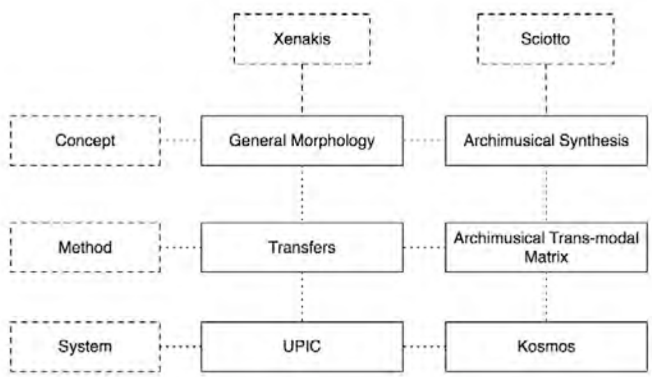

Figure 56: Xenakis and Archimusical Synthesis Diagram

The developments of this research on archimusical synthesis aim to build upon the principal developments of Xenakis. The computational compositional tool *UPIC* and its ability to employ the modal *transfers* are similar to the compositional tool *Kosmos* and its incorporation of the *Archimusical Transmodal Matrix,* while *Archimusical Synthesis* is focused on a similar goal as Xenakis' *general morphology.*

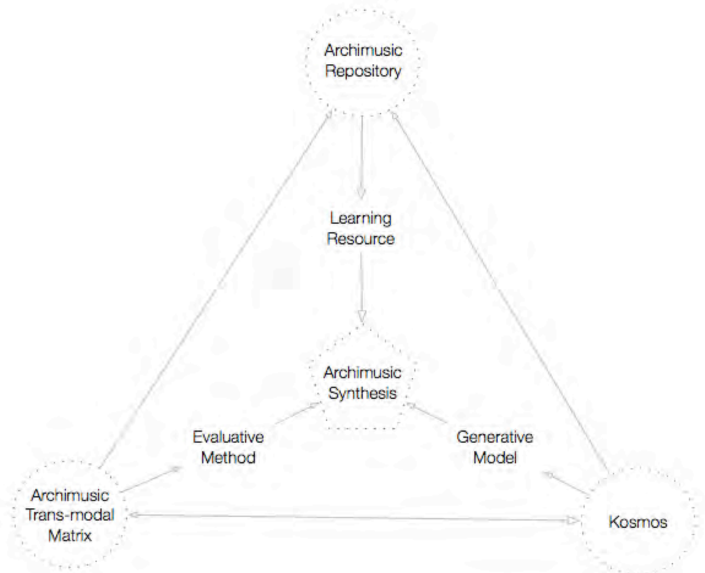

Figure 57: Research Structure

This research approach is triangular in nature, uniting the three research developments and the connections in the forming of *Archimusical Synthesis*. The *Archimusical Repository* (AOR) will illustrate the learning resource concerned with organizing and documenting necessary knowledge of the field. The *Archimusical Transmodal Matrix* (AmTM) will illustrate the evaluation method interested in mapping multimodal works and processes. *Kosmos* will illustrate the generative system component concerned with the composing and making of new archimusical works.

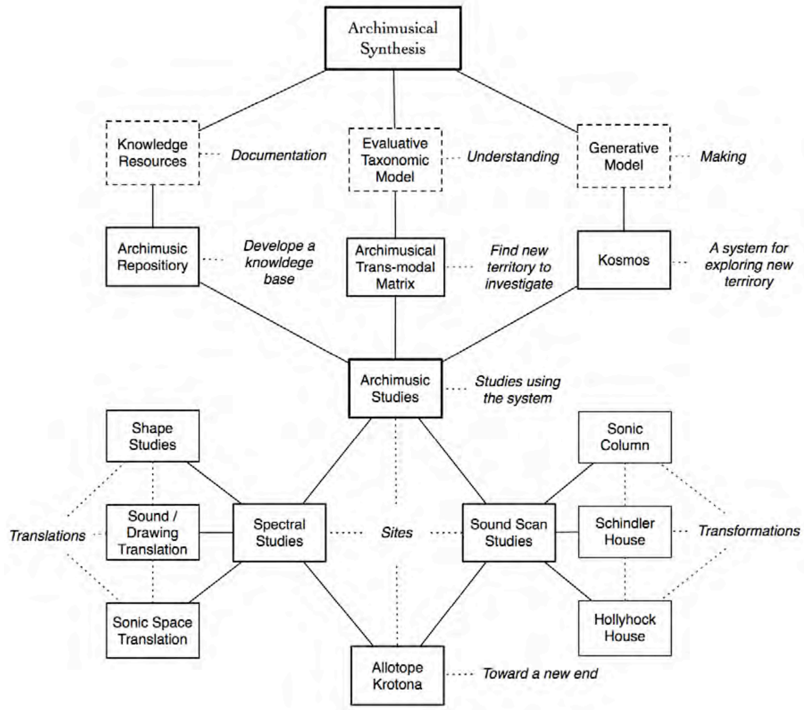

Figure 58: Expanded research structure diagram

3.2 Introduction to the Contributions

The three contributions of this research (*Archimusic Repository, Transmodal Matrix, and Kosmos*) aim to lead to new ways of thinking and making within this trans-disciplinary domain of archimusic. These contributions are introduced next and are discussed in detail in the following section.

3.21 Knowledge Resource: The Archimusic Repository

The first development is a comprehensive archimusic learning resource for trans-disciplinary knowledge necessary to the field that will help nurture the continued study of archimusic by others. The *Archimusic Repository* consists of an online and physical component, the *Archimusic Online Repository* (AOR) for the organization and framing of the archimusical field for the continued research and study of the field, and a set of physical readers (*Archimusic Readers*) that present the most important readings relevant to the topic of archimusic. The *Archimusic Repository* presents a solution to the need for a learning resource for those interested in and conducting research on the subject of archimusic. The goal of this development is to collect and organize works and studies found in over 150 different sources into one place to serve as a knowledge resource and support the dissemination of the topic of archimusic for those interested in continuing this research and incorporating it into teaching curriculums.

The *Archimusical Repository* includes a survey of projects (architecture, music, and art), people (architects, composers, and artists), and literature (architectural, musical, and philosophical texts) that have contributed to the historical lineage of the archimusical field with an accompanying interactive timeline. A selection of archimusic readers, designed to provide students, researchers, and teachers with an informative resource for the continued study and investigation of archimusic, is included in the repository.

3.22 Evaluative Method: The Archimusic Transmodal Matrix

The second development is an evaluative taxonomic method to analyze the modal integrations of trans-disciplinary works at the intersection of architecture and music. The *Archimusical Transmodal Matrix* is an ordering method to understand the transformational processes that an archimusical work embodies. The goal of this evaluative taxonomic method is to map and catalog the starting and ending points, and the transformational processes of an archimusical work. The *Archimusical Transmodal Matrix* evaluates archimusical works that allow us to understand their significance to other works and aims to give new direction for investigating and advancing the field.

The field of archimusic is composed of three main components, disciplines (the territory that the modality exists within), modalities (the expressed forms of the disciplines), and domains (the digital or analog type of each modality). This information is assembled into a matrix diagram whereby a path can be drawn illustrating each integration present in an archimusical work. The connection path allows for a better understanding of the trans-disciplinary and transmodal integrations.

3.23 Generative System: Kosmos

The third development is a generative system for the synthesis of new archimusical works informed by the aforementioned evaluative method. *Kosmos* is a proof-of-concept system, which demonstrates a fluid workflow whereby the materials and processes of these modalities are abstracted and treated as a liquid form able to exist in all modalities at once. The goal of this system is to enable the modal transformations of the digital and analog fields of architecture and music.

Kosmos has been developed as a generative archimusical synthesis system that will support the synthesis of new archimusical works by integrating the digital modalities of architecture and music by using the spectrum as the transformative mediator. *Kosmos* seeks to compose works based on findings from the *Archimusical Transmodal Matrix* and enable the composition of new archimusical integrations that will help explore the most promising territory further.

Additionally, a selection of *proof-of-concept* studies called the *Archimusic Synthesis Studies* are conducted with using Kosmos and will illustrate new directions and integrations. These studies explore the interconnected relationships and aim toward new transformations and integrations of archimusic.

4. Archimusic Contributions

"Music, like architecture, is an immersive experience; it surrounds you. One can turn away from a painting or a work of sculpture, while music and architecture engulf the body in space. Research into music and architecture moves forward at a time when architectural pedagogy is diffused, worn out. Schools of architecture today seem directionless. Postmodernism and deconstruction have passed into history, while the euphoria of technique in "parametrics" promises a lack of idea and spirit, and neglect of the importance of scale, material, detail, proportion, and light. Yet we continue to see potential in future architecture as open to experiment and as connected to spirit. While we ask, "what is architecture?" we also ask, "what is music?"

~ Steven Holl (Holl S., 2013)

The three archimusical developments introduced in the last section (*Archimusical Repository*, *Archimusical Transmodal Matrix*, and *Kosmos*) work together to create a unique method of organizing, evaluating, and generating work in this trans-disciplinary field. In the following section, we will describe each of these three developments. First, the *Archimusical Repository*, which is a knowledge resource for the study of archimusic. Next, the *Archimusical Transmodal Matrix*, an evaluational method for understanding the trans-disciplinary and transmodal integration of an archimusical work. Finally, *Kosmos*, a generative system for composing new archimusical works.

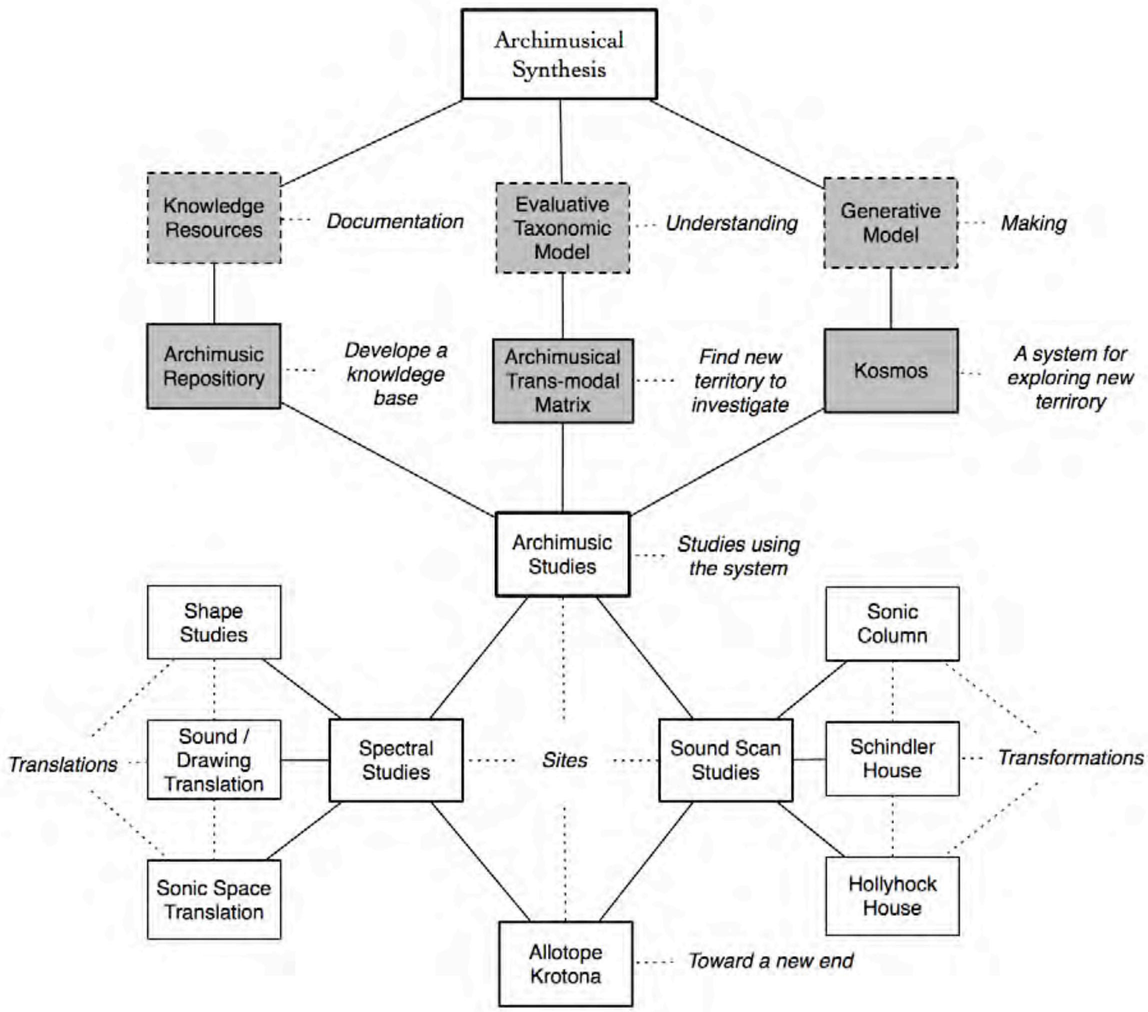

Figure 59: Archimusic Research Outline

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4.1 Contribution 1: The Archimusic Repository

The Archimusic Repository is a knowledge resource that consists of an online collection of archimusical works accompanied with an interactive timeline, a blog and a set of readers on the subject of archimusic. The goal of this collection is to bring together works and studies from 150 different sources in one place and to serve as a comprehensive resource for researchers and students interested in the study of trans-disciplinary works and the relationship between architecture and music.

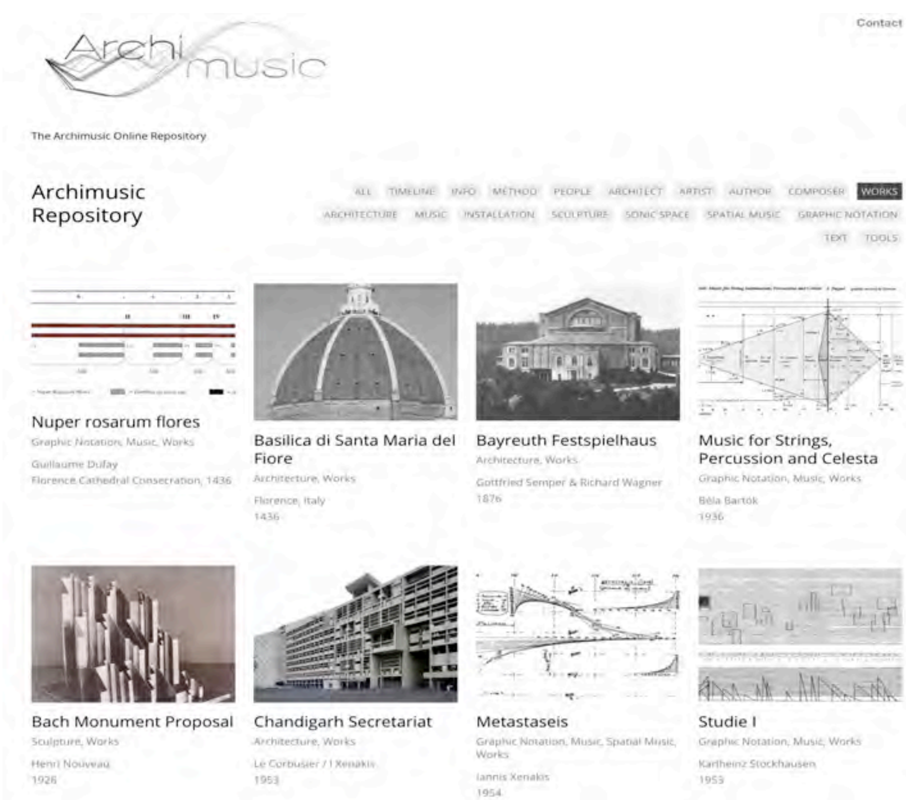

Figure 60: Front Page of the Archimusic Online Repository

The Archimusic Repository is a knowledge resource for learning about the field of archimusic, its history, contributors, and important related trans-disciplinary methods. During the process of this research, an enormous amount of time was spent searching and collecting necessary information for formulating a perspective and hypothesis on how to frame and advance this field. Had a resource like the Archimusic Repository existed, it would've been incredibly helpful and expedited the research process. The Archimusic Repository is a significant contribution for researchers, students, and other curious minds conducting research on similar intersecting topics by aiding the search for information regarding archimusic and trans-disciplinary methods between the fields of architecture and music.

This section will describe the two central components of the Archimusic Repository. The first is an online website called the *Archimusic Online Repository (AOR)*, and the second is a series of physical readers called the *Archimusic Readers*.

4.11 The Archimusic Online Repository

The *Archimusic Online Repository (http://archimusic.info)* is a website designed for the reference and study of the archimusic field. This online repository is organized into three components. The first is a cataloged survey of all people and projects related to archimusic. The second is an interactive timeline of the mentioned works and studies, which places the works in chronological and typological order. The third is a research blog that has been ongoing throughout the duration of this research and regularly posts information on news, events, projects, people and studies that are aligned with the archimusical field. The AOR has been developed for the informed progression, advancement, and continued study of the archimusical field. It has been designed and built with the intention of expanding and updating each of these online components in the future, including by other researchers and students.

4.111 Archimusic Website

The AOR is built on the *WordPress* platform to assure a thriving and sustainable online ecosystem and is hosted on the servers at the University of California, Santa Barbara. The domains *archimusic.info* and *archimusic.org* have been acquired and is linked to the repository; making it accessible during online research, easy to incorporate into web-based projects, and expandable into a research publication on archimusic.

The AOR is organized with a collected survey of the projects and people that have contributed to the field of archimusic. Each page on the repository gives an informative outline of the specific project, person, text, or method. The information includes details such as the date, location, and the photos and videos that were used in case of installations and musical compositions. Links to additional important and relevant information are provided, and each page is embedded with a *Wikipedia* page where open source information is available. Wherever possible, the information is hyperlinked to other related pages within the repository.

Figure 61: Archimusic Online Repository Searchable Sections

The background chapter (Section 2) provides a thorough overview of the major processes, methods, projects, and people involved in this dissertation and is therefore integrated in the AOR. The aim of including this section is for students and researchers interested in the trans-disciplinary integrations between architecture and music to understand the background of the field and where possible future areas of advancement may lie.

The cataloged survey of archimusical people and projects are organized into the following searchable categories:

- Architects
- Architectural Works
- Composers
- Musical Works
- Artists
- Artistic Works
- Studies
- Authors
- Texts
- Tools
- Graphic Notation

- Spatial Music
- Sonic Spaces
- Sculptures
- Installations

A cataloged survey of the archimusical methods, relationships, and integrations are organized into the following searchable categories:

- Aural Architectures
- Soundscapes
- Sound Sculptures
- Cymatics
- Architectural Acoustics

**Note: The full survey of archimusical people, projects, and methods can be found in the Appendix.*

4.112 Archimusic Repository Timeline

An interactive timeline of the above-mentioned projects accompanies the archimusic website. The timeline enables ease of searching for the surveyed people and projects using a User Interface (UI) slider organized into six linear categories as follows: *Architects*, *Architecture*, *Artists*, *Composers*, *Music*, and *Texts*. Along the bottom of the timeline, labels are given identifying the historical period when the particular work was written, built, or composed. These include the *Ancient Greece, Ancient Roman, Romanesque, Gothic, Renaissance, Baroque, Neoclassical, Victorian, Modern, Beaux*

Arts, International, Structuralism, Post-Modern, Deconstruction, High-Tech, and Contemporary times.

The timeline is built using a *JavaScript* plugin for *WordPress*, enabling the platform to be continued and passed along to other institutions for further advancement should the opportunity arise. Each element in the list is inputted into an .XML file. Just as the survey is an ongoing process, so is the archimusic timeline. As new projects are added to the survey, they will be included in the timeline.

Figure 62: Archimusic Timeline front-page

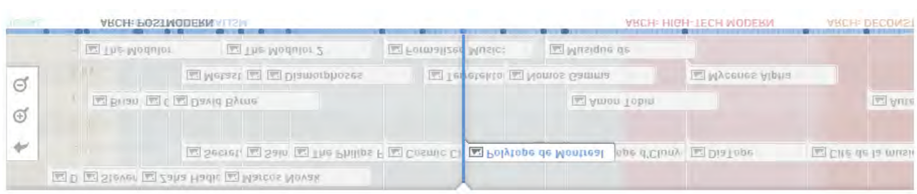

Figure 63: Archimusic Timeline Front-Page & Scrollable Categories

4.113 Archimusic Repository Blog

A blog about archimusic is the third component of the AOR. This blog is regularly updated and posts ongoing events and information regarding projects, competitions, proposals, and conferences. The *Archimusic Repository Blog* is hosted on *Tumblr* and embedded in the AOR to enable ease of moving back and forth between the two sites.

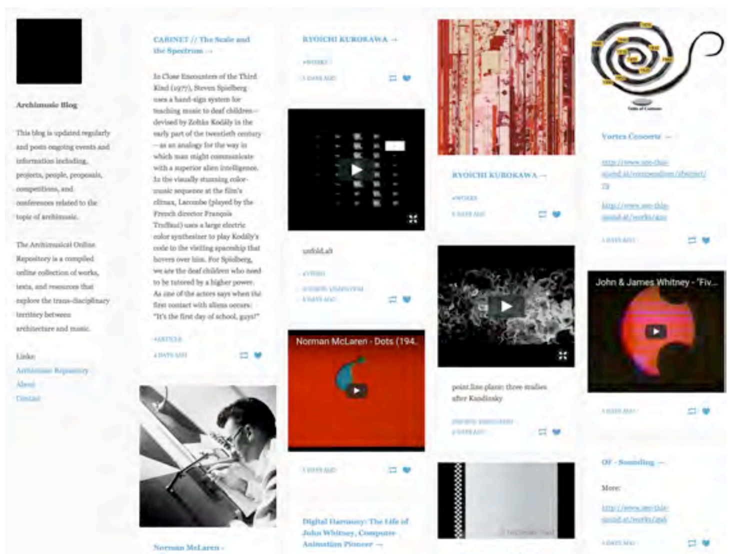

Figure 64: Screenshot of the Archimusic Online Repository Blog

4.12 Archimusic Readers

The final component of the AOR is a comprehensive six-volume reader series composed of critical writings, essays, and book chapters by a wide range of authors who have explored the relationships between architecture and music. These archimusical readers contain a thorough bibliography and reference list of other relevant information that can be found on the topic. Currently, three physical spiral copies are in existence. The first is in the author's possession and will be used for teaching in studios that focus on the role of sound and music within architecture. The second copy is in possession of the Media Arts and Technology Program (MAT) at the University of California, Santa Barbara. The third copy is in possession of the Southern California Institute of Architecture (SCI-Arc) Library in Downtown Los Angeles. Compiled digital files also available and linked in the AOR.

Figure 65: Volumes of the Archimusic Readers

4.121 Reader Volumes

The *Archimusic Readers* have been compiled to cover the field of archimusic in six volumes, with each volume focusing on different sub-topics. The six volumes aim to categorize the components of archimusic for the systematic study of the field as a whole.

Each of these six readers contain eleven readings that have been carefully selected as the most relevant papers, essays, and book chapters on each of the sub-topics. In addition, there is a reading list at the end of each volume referencing additional reading on each subject. The six volumes are as follows:

- Volume I – Architecture and Music

  Volume I focuses on directly exploring the concept of archimusic, providing readings on the subjects between architecture and music.

- Volume II – Notation and Instrumentation

  Volume II focuses on exploring the concepts of archimusical notation and instrumentation. It provides readings on the graphic and software aspects and the methods of motion, time and creative process.

- Volume III – Transformation and Composition

  Volume III focuses on exploring the concepts of transformation and composition within archimusical work and processes, providing readings on the compositional methods and transformational logic.

- Volume IV – Archimusical Works of Iannis Xenakis

  Volume IV focuses on the Archimusical Works of Iannis Xenakis and provides readings on his works and creative processes, in both Xenakis' words and the words of Xenakis experts.

- Volume V - Philosophical Considerations

  Volume V focuses on exploring the philosophical considerations of archimusic and provides a discussion on the topics of art, proportion, and technology from ancient to contemporary times.

- Volume VI - Translational and Transformation Studies

  Volume XI focuses on the translational and transformation studies of archimusic and currently exists in three sub-volumes, providing over 150 studies including theses and projects pertaining to archimusic.

As with the Archimusical Online Repository, this research intends that the Archimusic Readers be maintained and updated, adding additional essays, chapters, and volumes as needed. The Archimusic Readers are aimed to collect the existing wealth of knowledge in one place for future advancement in the field.

**Note: The table of contents of each of the Archimusic Reader volumes can be found in the appendix.*

4.13 Summary

The goal of the Archimusical Repository is to bring together works and studies found in over 150 different sources to one place and serve as a comprehensive starting point for anyone interested in the relationship between architecture and music.

In this section, we have described the two components of the Archimusic Repository. The first includes the online components of the AOR, website surveying the people, projects, and information involved with archimusic, the interactive timeline that supports the chronological display of the information and a research blog that posts news, events, and information involving the field. The second component described is the Archimusic Readers, which have been assembled as a six-volume series that cover the field of archimusic by subdividing it into topics, including Architecture and Music, Notation and Instrumentation, Transformation and Composition, Archimusical Works of Iannis Xenakis, Philosophical Considerations, and Translation and Transformation Studies. These readers are designed to provide students and researchers with an informative resource for the extended study and investigation of the archimusic field.

The Archimusic Repository organizes and frames the archimusic field, serving as a knowledge resource and supporting the dissemination of the topic of archimusic for those interested in continuing research and incorporating it into teaching curriculums.

4.2 Contribution 2: The Archimusical Transmodal Matrix

The *Archimusic Transmodal Matrix (AmTM*) is a transmodal method for understanding the transformational processes and modalities of archimusic works. This method will enable the mapping and classification of the processes and interactions embodied in the making of works that integrate the fields of architecture and music with the goal of understanding and cataloging the starting point, ending point and the transformational processes that each work embodies.

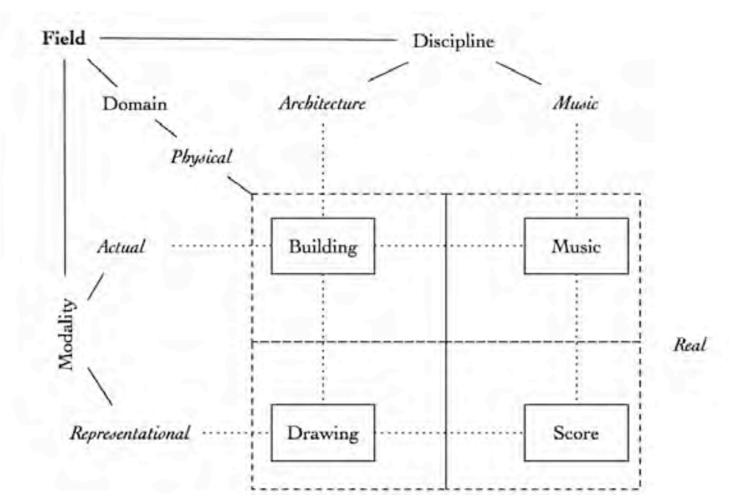

Figure 66: The Archimusic Transmodal Matrix

The Archimusical Transmodal Matrix is an evaluative method for analyzing the different translations, associations, and transformations of an archimusical work. It enables us to properly identify the different relationships and integrations that are present in the project. In tracing these different processes, we can better understand the project as a whole. Since the project becomes an assemblage of relationships and integrations and exhibits particular types of paths we can, therefore, have a metric with which projects can be compared and contrasted to another to better understand the territory explored throughout the range of all archimusical work. It cannot be claimed that by using only this method, the entire field can be understood. However, it is in the opinion of this research that it will be an integral tool in helping to achieve this goal.

In this section, we will present the Archimusical Transmodal Matrix and describe its components, organization, and how it works to achieve a thorough understanding of the trans-disciplinary processes and unique integrative paths of an archimusical work.

4.21 The Disciplines, Modalities, and Domains of the AmTM

The Archimusical Transmodal Matrix is a three-dimensional matrix consisting of three different planar dimensions. The X-axis represents the *disciplines*, the Y-axis represents the *modalities*, and the Z-axis represents the *domains*. This matrix structure is designed so that as many possible types of archimusical projects can be categorized within a taxonomic framework to analyze their components and characteristics. Mapping these disciplines, modalities, and domains allow the understanding of the trans-disciplinary relationships and processes.

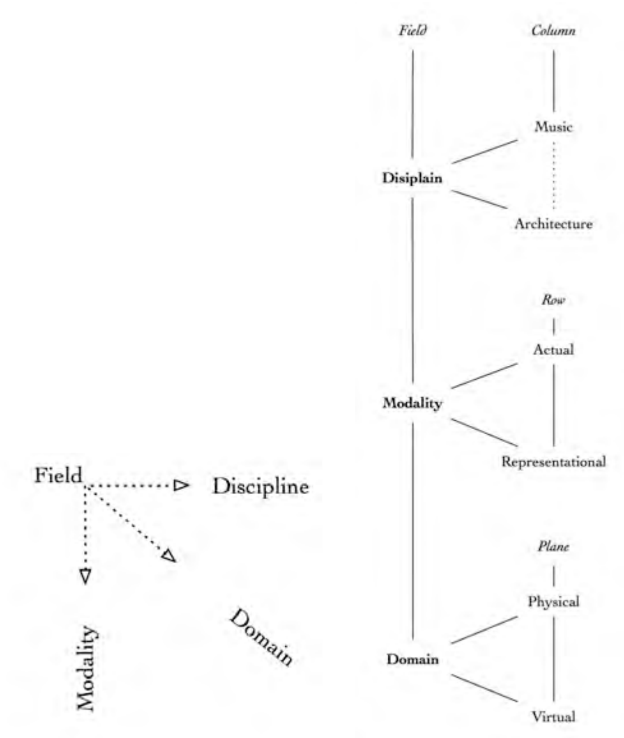

Figure 67: The axis and components of the AmTM

4.211 Disciplines – X-axis (A = Architecture, M = Music)

The *disciplines* are the branch of knowledge to be used within AmTM; in the present case of archimusic, the disciplines are *architecture* and *music*.

- The *discipline* of *architecture* is commonly defined as the building of structures made for inhabitation. In this research, we use the term *architecture* to mean the physical or virtual composition of structural elements into ordered relationships in or through the dimension of space.

- The *discipline* of *music* is commonly defined as the organization of sounds into relationships that have emotional effect. In this research, this definition is expanded to include the physical or virtual composition of harmonic structures in or through the dimension of time.

4.212 Modalities - Y-axis (a = actual, r = representational)

The *modalities* are the particular mode or form in which the disciplines mentioned above are experienced or expressed. In the AmTM, the modalities are *actual* or *representational*.

- The *actual modality* is the embodied form of the respective discipline. The actual modality can be understood as the structure of a building, in the case of architecture, or the sound created by an instrument in the case of music.
- The *representational modality* is the referential form of the respective discipline. The disciplines of architecture and music have a unique relationship in which they each have a corresponding representational form; drawings or plans in the case of architecture, and scores or notation in the event of music.

4.213 Domains – Z-axis (p = physical, v = virtual)

The domains are the territory where the specific modality of the specific discipline exists. The domains of the mentioned modalities used in the AmTM are considered either *physical* or *virtual*.

- The *physical* domain is the material realm of a modality where the form exists within the real material reality.
- The *virtual* domain is the computational or simulated realm of a modality where the form exists within computational virtuality.

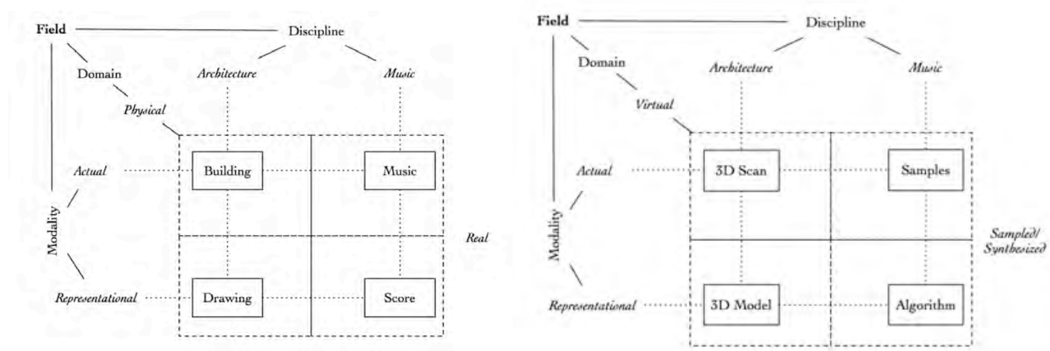

Figure 68: The Physical and Virtual Domains of the AmTM

4.214 The Matrix and Modal Representations

Each cell of the AmTM is called a *modal element.* A modal element represents a particular domain of a particular modality of a particular discipline. For example, the modal element of a building would be the *physical domain*, of the *actual modality*, of the *architectural discipline [pa(A)],* while a musical score would be the *physical domain*, of the *representational modality*, of the *musical discipline [pr(M)]*. The below figure is a diagrammatic example of what each cell (modal element) is representative of, along with a figure illustrating all layers of the AmTM combined.

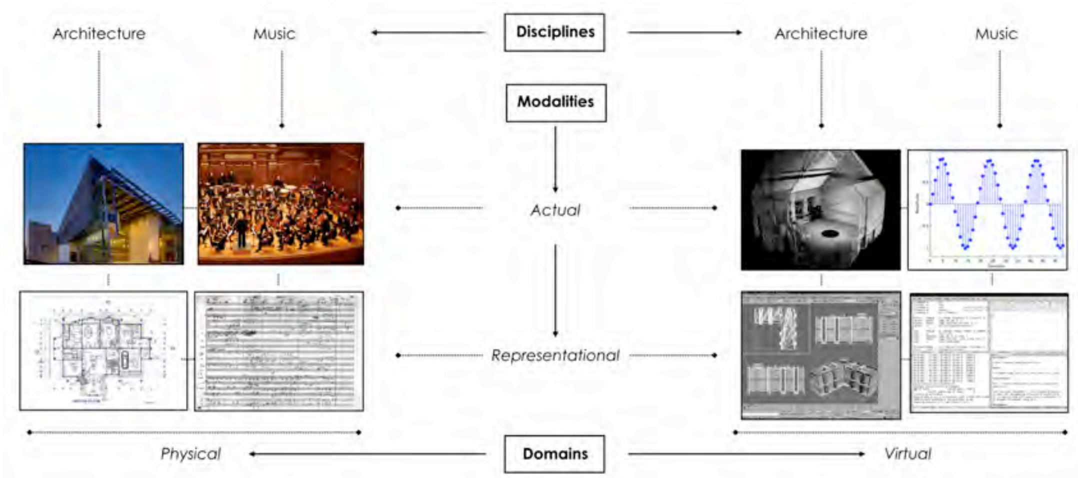

Figure 69: AmTM representative examples

While all the modal elements are of interest in the investigation of new archimusical methods, the digital modalities will be the primary focus. These modalities include the physical and virtual modal elements and data types of both architecture and music including the following:

- va(M) – Virtual Actual Music - Audio files (.wav, .mp3)
- vr(M) – Virtual Representational Music - Midi files (.mid)
- va(A) – Virtual Actual Architecture - 3D scan files (.xyz, .obj)
- vr(A) – Virtual Representational Architecture - Drawing files (.dwg)

Real-time data modal elements include:

- va(M) – Virtual Actual Music - Real-time audio from microphones - Digital-to-analog converter (DAC)

- va(A) – Virtual Actual Architecture - Real-time spatial data from 3D Scanner - 3D camera (Microsoft Kinect)

The modal elements from the physical domains such as musical scores or architectural drawings include:

- pr(M) – Physical Representational Music - Scores (.jpeg)
- pr(A) – Physical Representational Architecture - Drawings (.jpeg)

4.22 Mapping the Unique Paths of a Transmodal Work

Works of archimusic are trans-disciplinary and transmodal, and the AmTM enables mapping these integrated processes. The AmTM allows mapping the starting point, ending point, and the individual processes used in the making of a work of archimusic. To map these processes, *vectors* are drawn onto the AmTM that represent the relationships between the disciplines, modalities, and domains of the modal elements. The *vector* is a representative path through the AmTM, illustrating the specific integrations within an archimusical work. This path allows for a better understanding of the trans-disciplinary and transmodal integrations by visualizing each step within one diagram. This diagram enables the relationships between different archimusical works to be compared and contrasted.

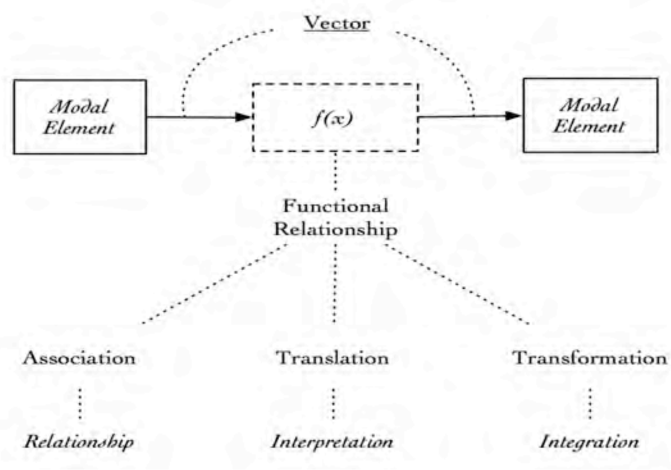

Figure 70: The AmTM Vector and Relationship Functions

The vector also represents a *functional relationship* that exists between connected modal elements. These *functional relationship* [*f(x)*] can be conventional, associational, translational, or transformation and when a connection is made across *disciplines* it should be notated on the AmTM as will be seen in future AmTM diagrams. The following diagrams illustrate these functional relationships.

Note: For ease of understanding, the following diagrams illustrate the physical domain.

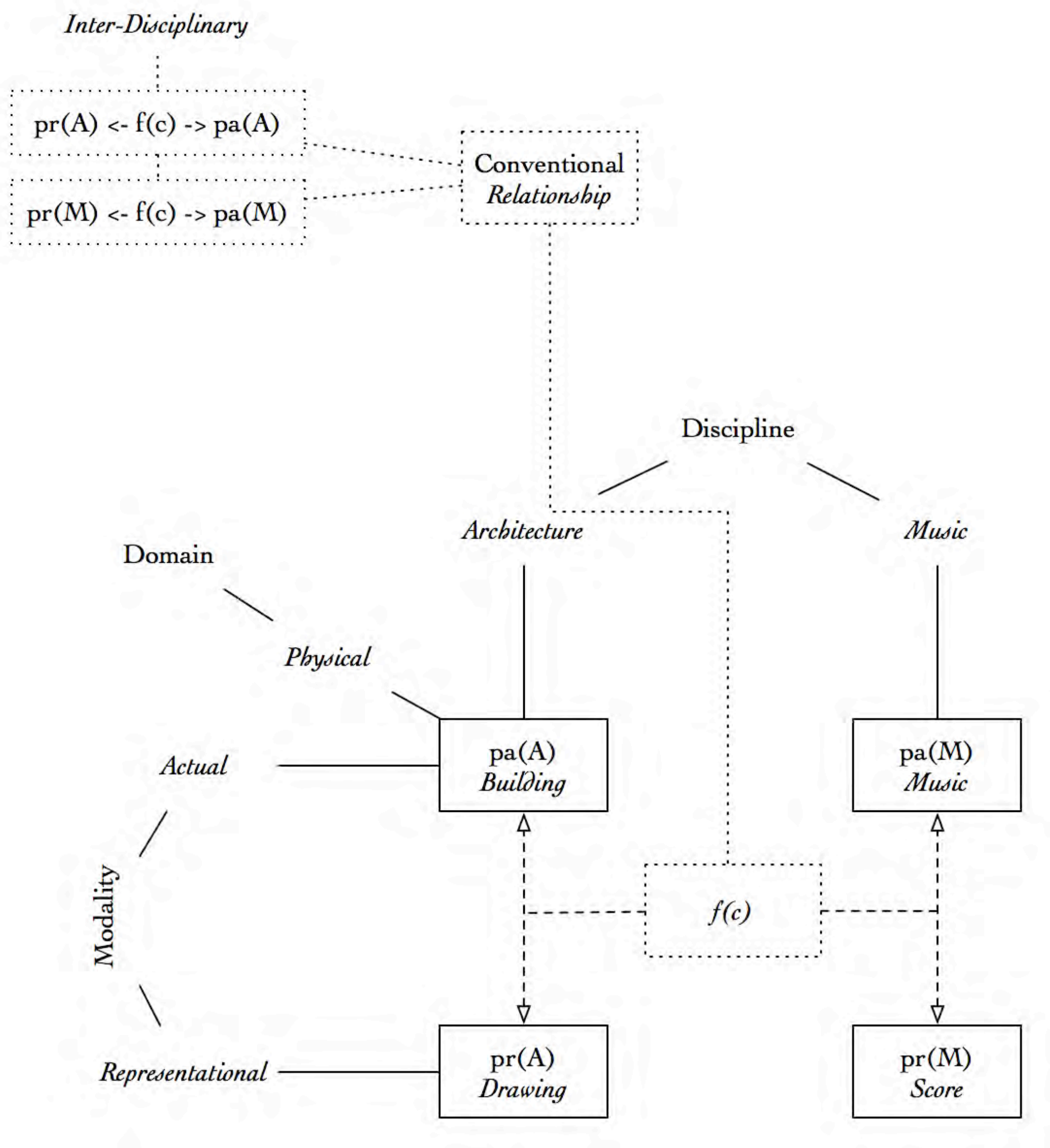

Figure 71: Conventional Functions

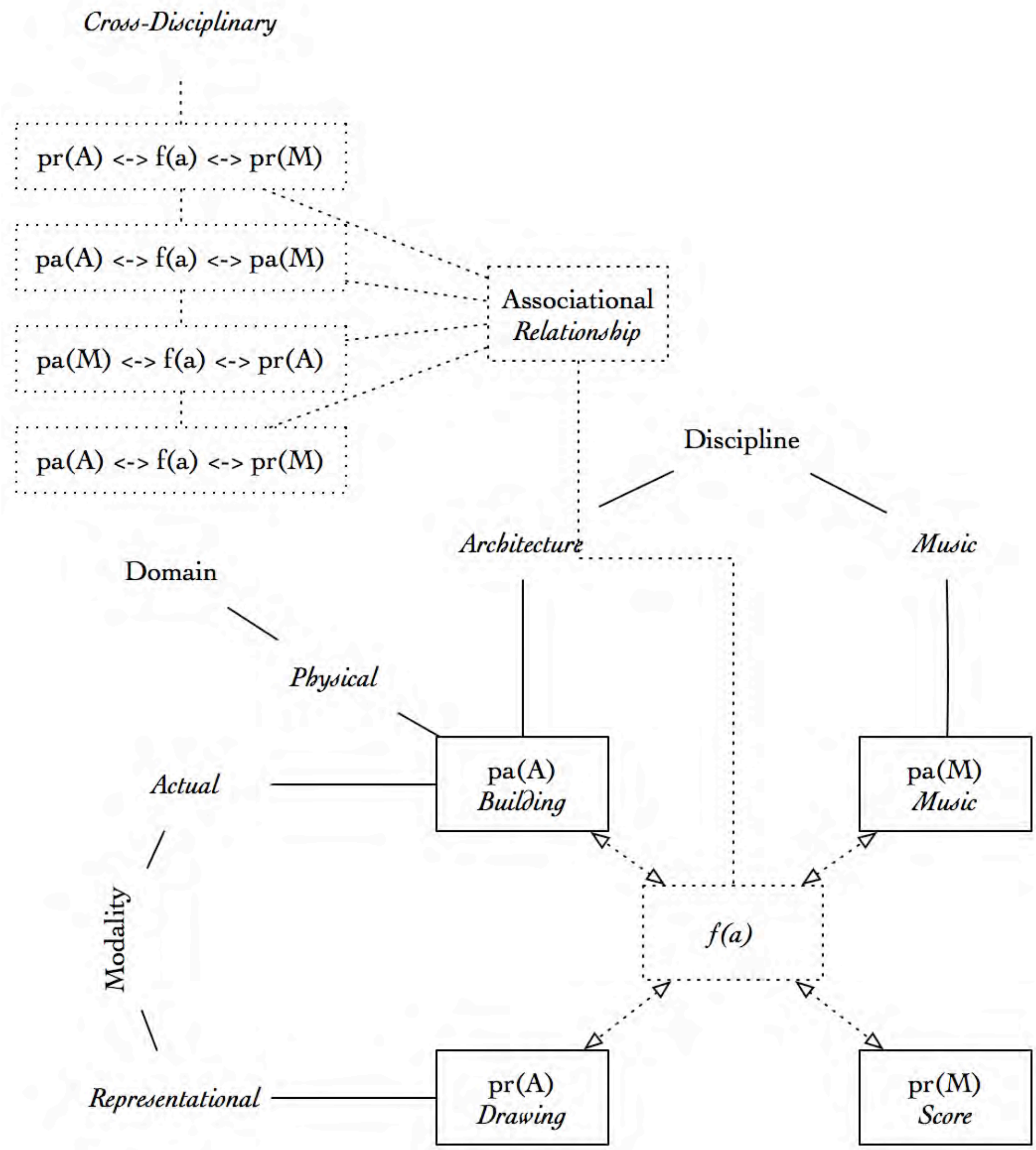

Figure 72: Associational Functions

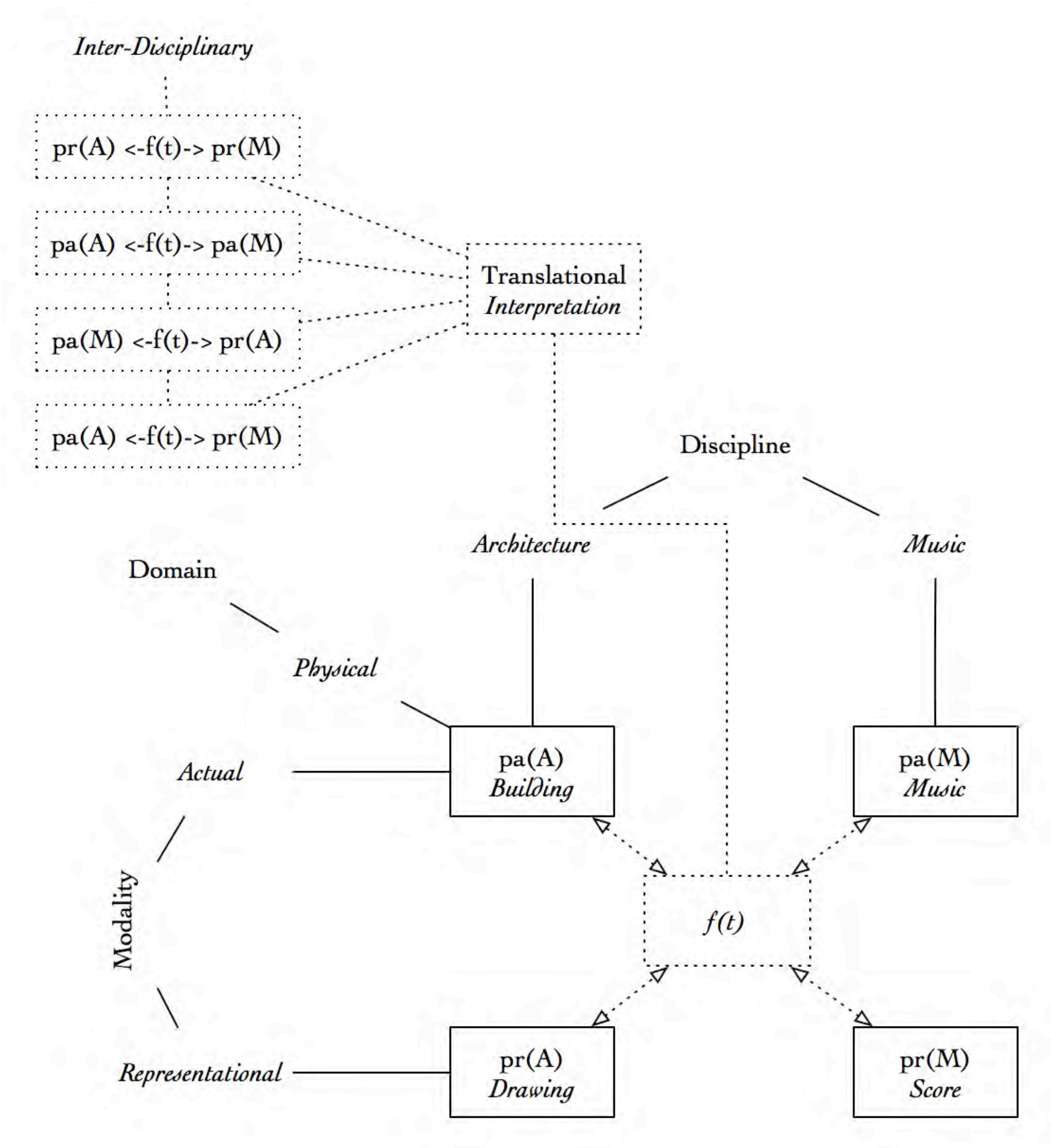

Figure 73: Translational Functions

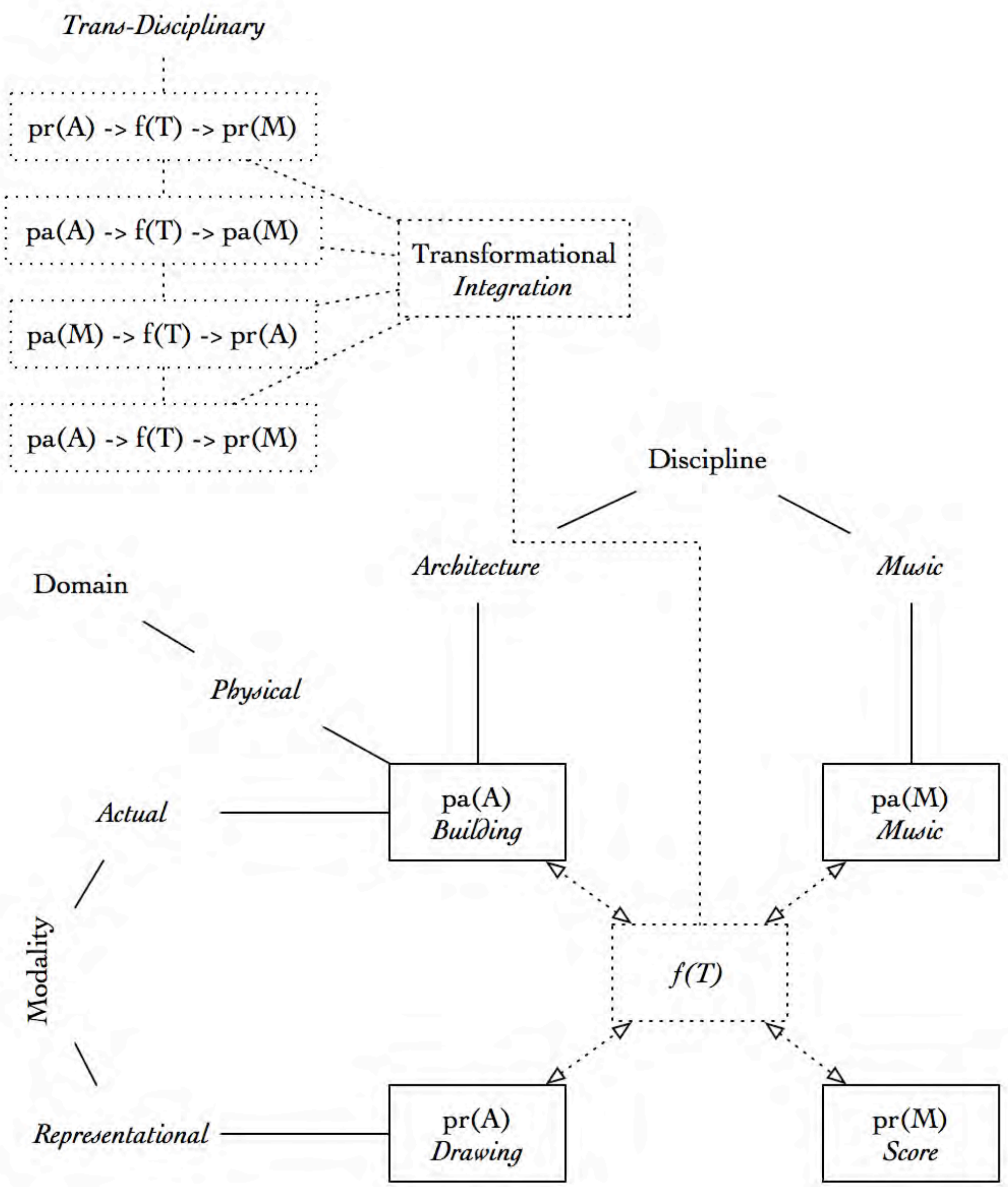

Figure 74: Transformational Functions

4.221 Integrations

By using the AmTM to map the processes of an archimusical project, the differences between *apparent* and *concrete* relationships become clear. To illustrate this critical difference, we can analyze Brunelleschi's Duomo of Santa Maria del Flores and its relationship to Dufay's Nuper Rosarum Flores. As discussed in Section 2.22, the relationship between these two works is translational; this example being between the *initial* modal element of the building [*pa(A)*], and the *destination* modal element of a piece of music [*pa(M)*]. At first, this apparent relationship could be mapped on the AmTM as follows:

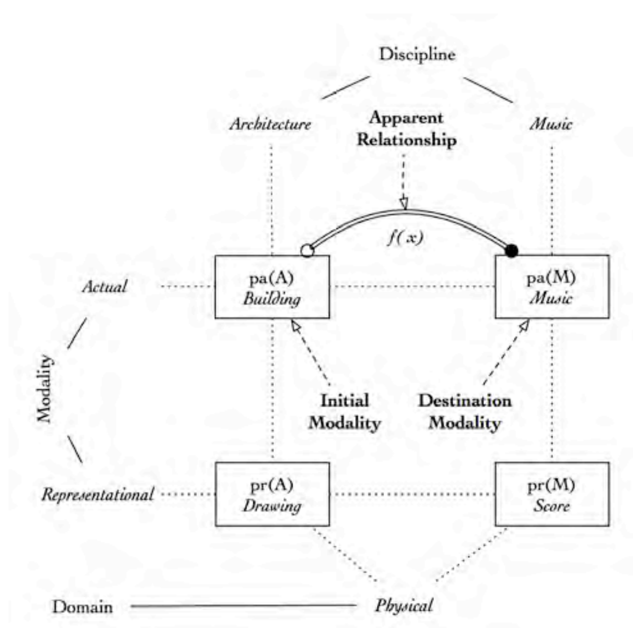

Figure 75: Apparent relationship

While the *apparent* relationship seems correct from a general perspective, the *concrete* relationship has a different path in achieving this translational relationship between the Il Duomo and Nuper Rosarum Flores. In the accurate AmTM map (Figure 76), we see how this translation unfolds with more resolution. The *initial* modal element of the physical Cathedral *[pa(A)]* begins by having a *conventional* relationship to its representational modality of a drawing *[pr(A)]*. Specific aspects (the vertical proportions of the structure) of the Cathedral's drawing are then translated *[f(t)]* (translational functional relationship) into the representational modality of a musical score *[pr(M)]*. The musical score then has a *conventional* relationship to the physical piece of music *[p(M)]*, which is the *destination* modal element and the end of the AmTM map.

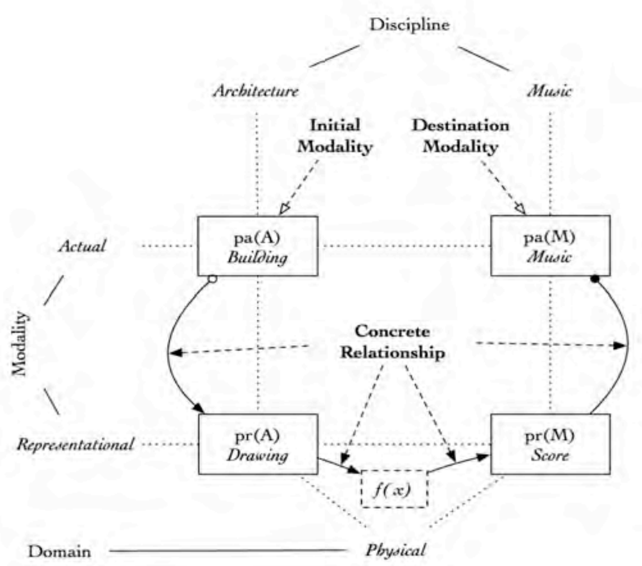

Figure 76: Concrete relationship

These extra steps are necessary to fully understand the individual concrete relationships involved in the development of this archimusical work and illustrate why the AmTM map is so useful in understanding the inherent transmodal processes. By assembling all the vector paths that represent the particular processes involved between each modal element we can have a coherent picture of how the work is generated and are now better able to relate it to other works.

4.222 Constellations

The previous example of the relationship between Il Duomo Firenze and Nuper Rosarum Flores is straightforward, being mapped in the physical domain only. Other examples are more complicated and need the physical and virtual domains to be adequately mapped. The following AmTM diagram of the Philips Pavilion is one example illustrating more complicated relationships.

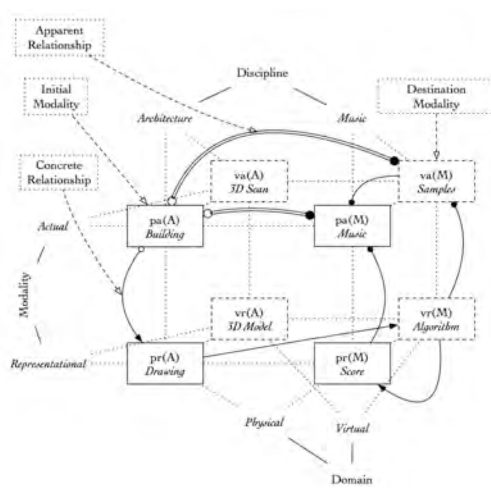

Figure 77: A complete AmTM map can be complex and difficult to read

The AmTM can become overburdened when mapping projects with many unique relationships and therefore it is necessary to represent the matrix more simply while still representing all the information correctly. This simplification is produced by flattening the 3D matrix as into what we refer to as an *AmTM Constellation* where each cell is identified by a node, connected by dotted lines that can be traced over to represent the modal relationship vector. The outer matrix of nodes represents the *actual* domain, while the inner matrix of nodes represents the *virtual* domain. A notated diagram of the AmTM Constellation is provided below along with a legend.

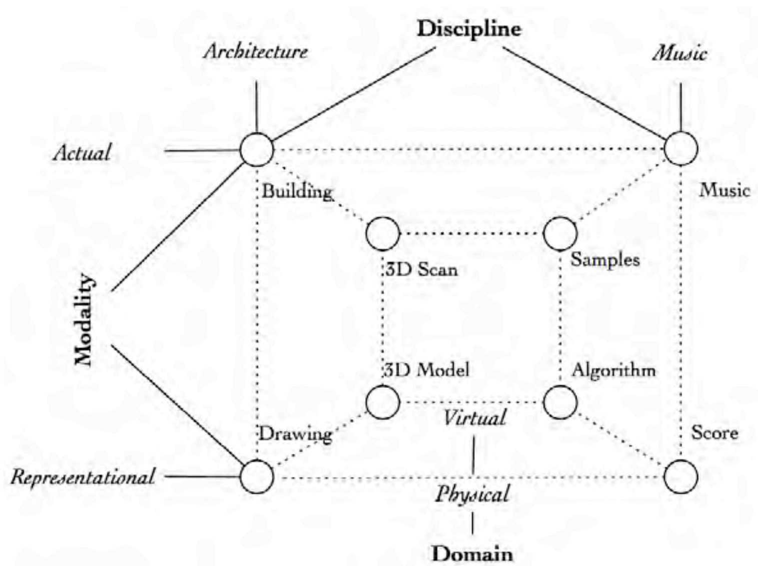

Figure 78: AmTM Constellation and nodal representations

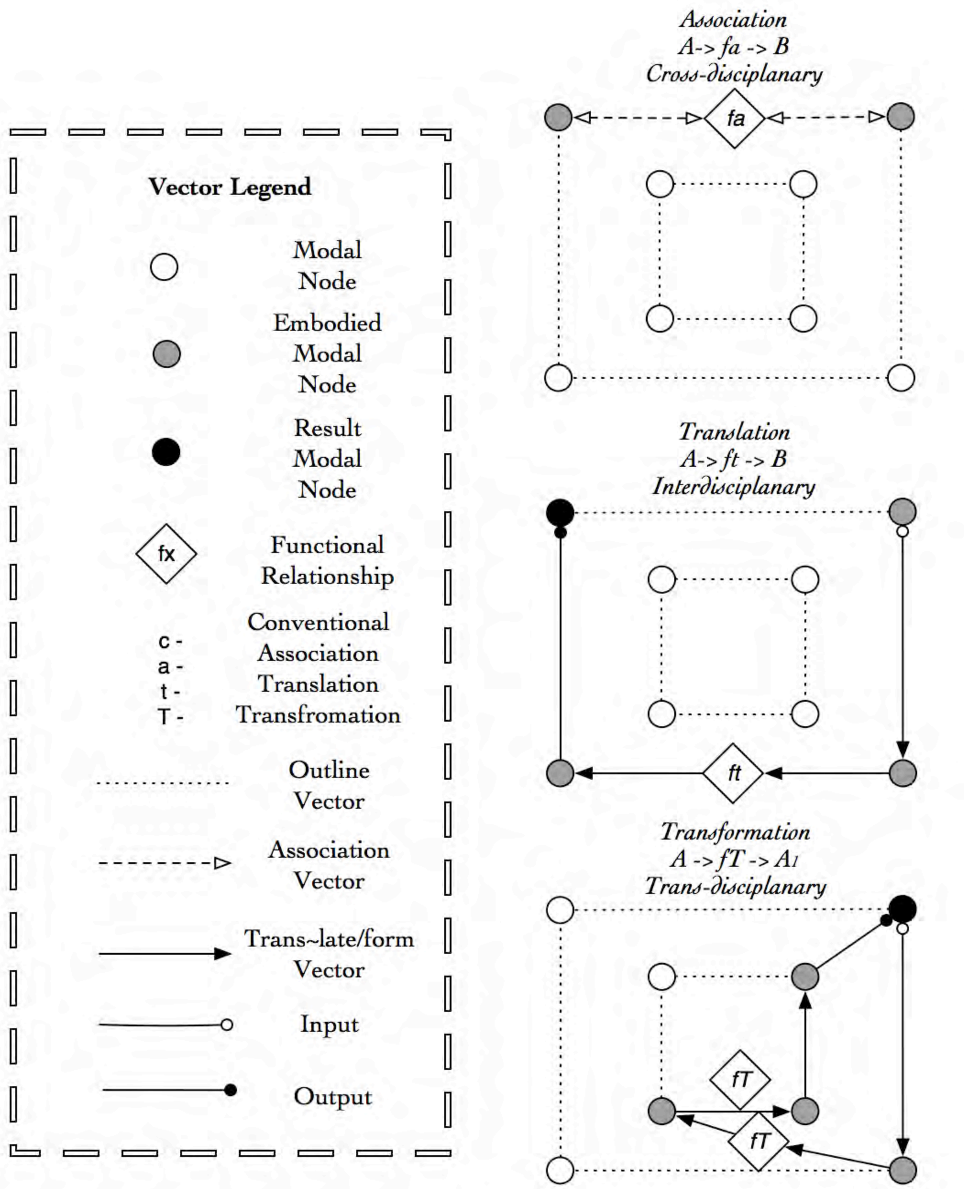

Figure 79: AmTM Constellation Legend with constellation examples of associational, translational, and transformational relationships

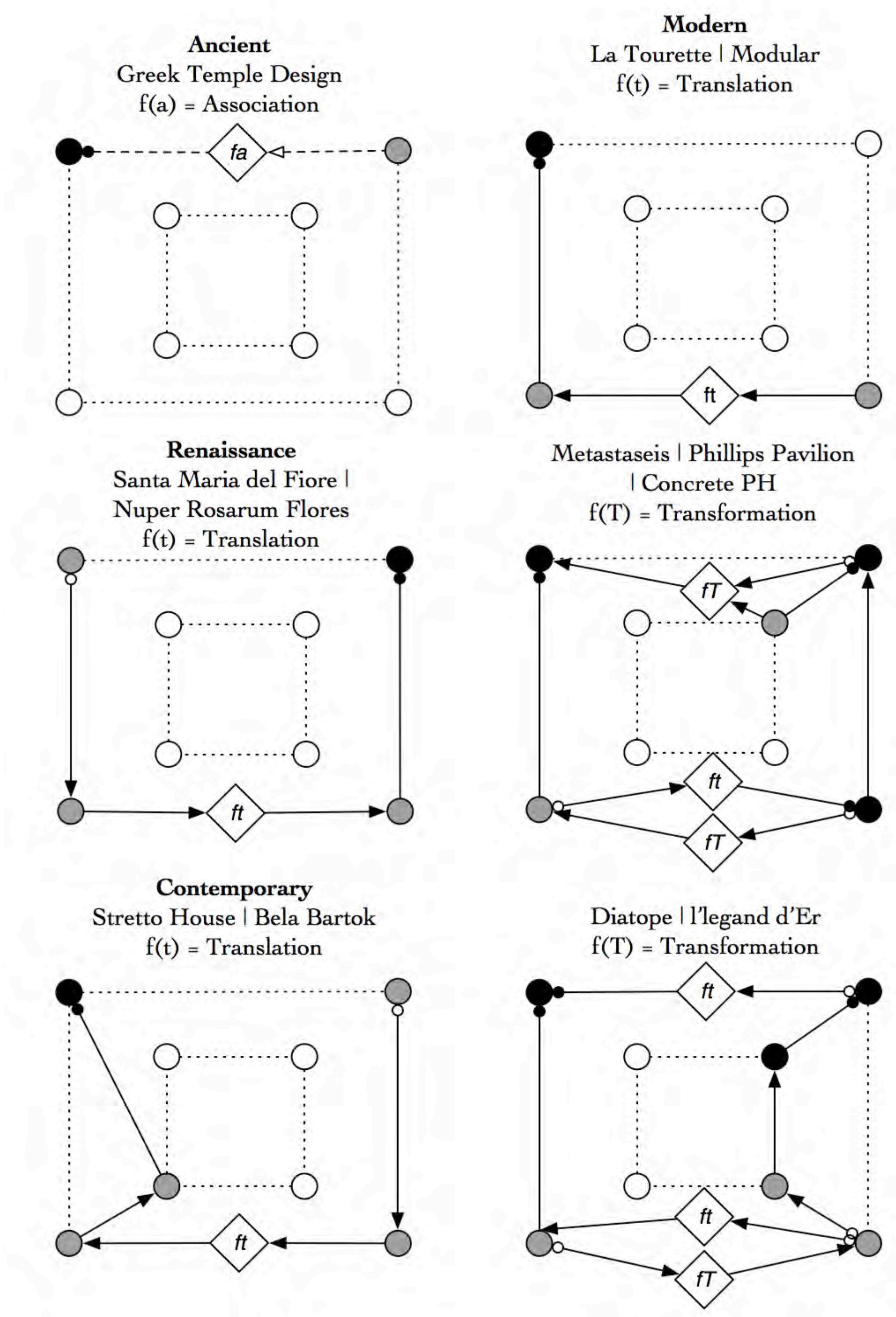

Figure 80: Archimusical Project Constellations

4.223 New Territory

Many of the projects presented in this research have been mapped using the AmTM, including the works of Iannis Xenakis, which are the among the most progressive. An essential finding of this research is while most of the paths and model elements have frequently used, one model element [va(A)] is absent. This finding leads us to incorporate this missing modal element to explore this new archimusical territory. The tools and technologies of 3D scanning and digital point clouds associated with [va(A)] are integrated into new transformational processes using Kosmos to advance the development of the archimusical field.

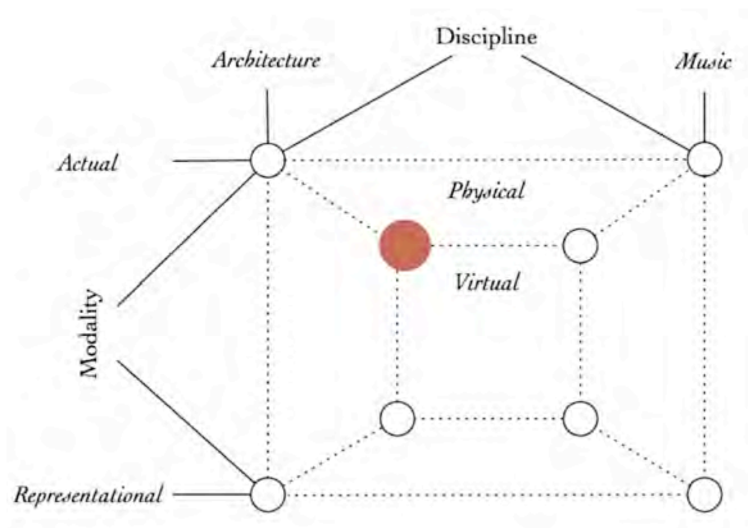

Figure 81: Constellations of new modal element to be integrated in future work

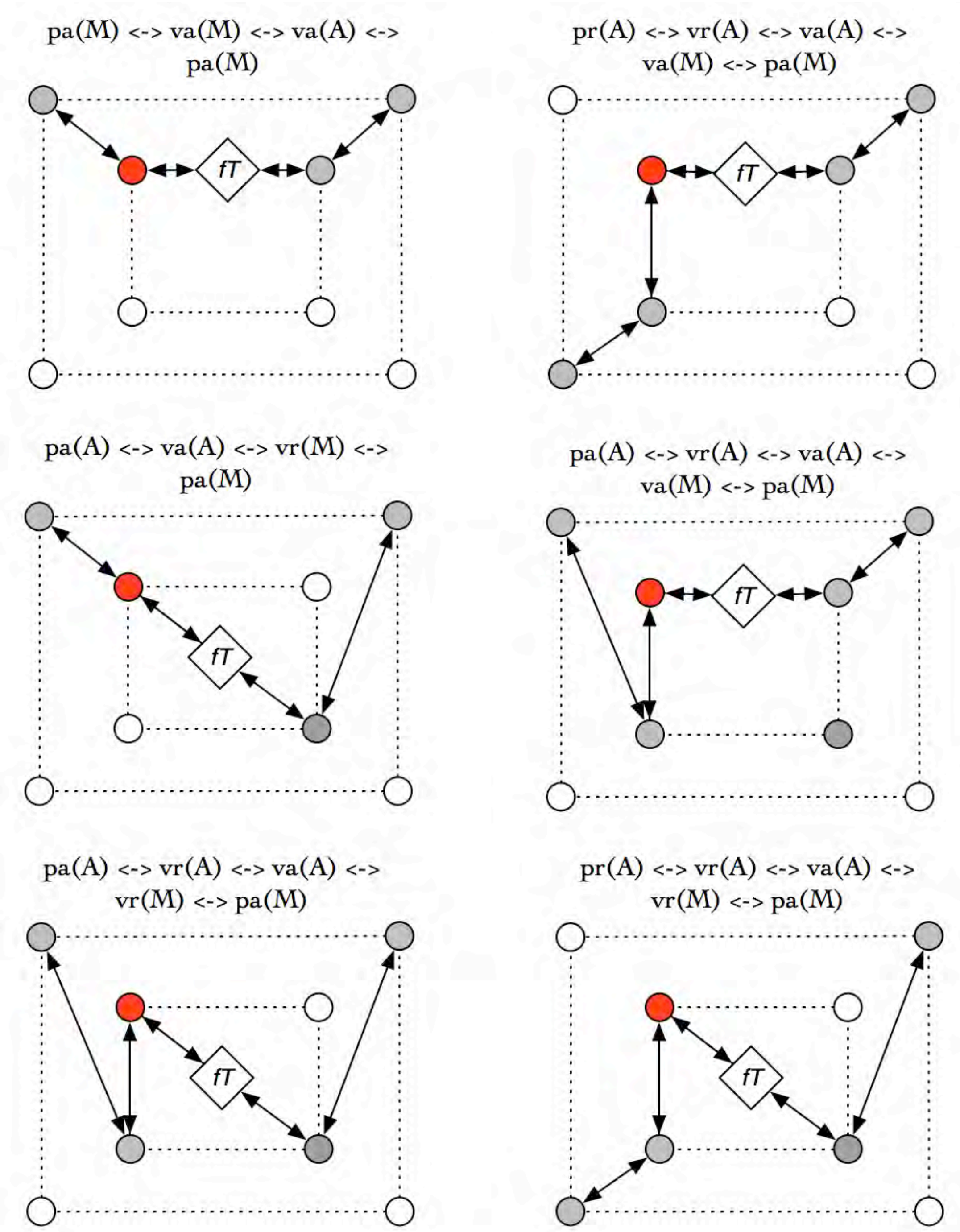

Figure 82: Constellations illustrating new transformations

4.23 Summary

The goal of the *Archimusical Transmodal Matrix* is to provide an evaluational framework to map and categorize the starting point, ending point, and transformational processes inherent in an archimusical work. In this section, we have described the layout of the *disciplines*, *modalities*, and *domains* of the archimusical field which create the structure of the AmTM and the different modal elements that are represented by the matrix. We then described the process of mapping the relationships between the *initial* and *destination* modal elements using *vectors* and *functional relationships*. These maps illustrate significant differences between *apparent* and *concrete* relationships to better understand the processes inherent in works of archimusic. The *AmTM Constellation* has illustrated how to map archimusical projects simply and elegantly, alongside projects of Iannis Xenakis for reference. Lastly, we have identified the modal element of [*va(A)]* (virtual domain, physical modality, architectural discipline) including 3D scanning and digital point clouds that offers new territory to explore future works. This exploration is accomplished using the generative system Kosmos which is presented in the next contribution of this research.

4.3. Contribution 3: Kosmos: Archimusic Synthesis

Kosmos is a proof-of-concept generative system, which demonstrates a fluid workflow whereby the materials and processes of these modalities are abstracted and treated as a liquid form able to exist in all modalities at once. The goal of this system is to enable the modal transformations that unify the digital fields of architecture and music.

Figure 83:The main interface of Kosmos

Kosmos integrates the digital modality of 3D point clouds and sonic recordings to generate new archimusical forms and enables the advancement of the field into new transformational territory using *spatiotemporal sampling* and *allograms*. In this section, we examine the approach of this archimusical synthesis tool and the techniques of an archimusical compositional system. We present the computational generative tool, Kosmos, including the concept of *archimusical synthesis*, the computational framework, and the parameters of Kosmos.

4.31 A Generative System for Archimusical Synthesis

Kosmos is a computational system developed with the intention to experiment with combining the digital modalities of architecture and music. Exploring how musical and architectural processes can influence one another are relevant conventions for the archimusical realm. This proof of concept generative system will support the synthesis of new archimusical works by integrating the digital modalities of 3D scans (point clouds) and sound recordings using the spectrum as the transformative mediator. Kosmos explores these possibilities within a computational framework with the aim of illustrating new methods and processes that help explore the new transformational territory and advance the archimusical field.

4.311 Archimusical Synthesis

Archimusical Synthesis is the method at the core of *Kosmos*, enabling the production of new archimusical transformations and integrations. Archimusic is a field framed by this research and a method for the synthesis of archimusic is presented to generate new works within the field. Archimusical Synthesis is a form of spatiotemporal synthesis created by integrating the spatial and sonic data into the same domain This is achieved by the methods of *spatiotemporal sampling* and the *allogram*, which enable a novel way of working in the archimusical field.

Spatiotemporal sampling uses the technology and techniques of 3D scanning, point clouds, and sonic recordings to explore the integration of spatial and sonic modalities, while the *allotope* aims to unify the sampled material for the composition of new spaces, sounds, and archimusical forms. These contemporary computational and compositional tools and techniques illustrate new digital approaches to the field of archimusic.

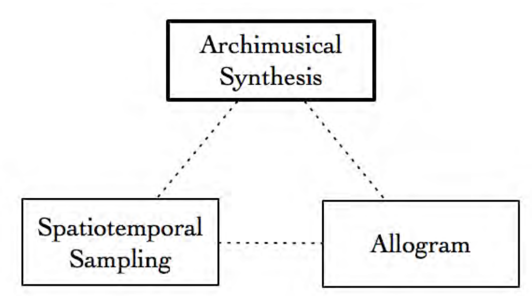

Figure 84: Archimusical Synthesis method diagram

4.312 Spatiotemporal Sampling

In this research, we use spatiotemporal sampling as a method to bridge the spatial and sonic parameters of a given space in the digital domain using both *sonic sampling* and *spatial sampling*. *Sonic sampling* uses microphones to record sonic information from spaces, while *spatial sampling* uses a 3D scanner to record spatial data from the physical objects and spatial structures. Archimusic is a space-time discipline, and these two forms of sampling are integrated to composing material which exists in both space and time.

Sonic sampling can be used to record the surrounding natural environment and the ambient atmosphere or the materiality of a space, such as wood, glass, or concrete. In this research, sonic sampling utilizes contact microphones to pick up the vibrations of the material to which they are attached, and condenser microphones, which pick up the sensitive frequencies of the ambient environment. The sounds can be recorded and cataloged for future composition or used as a real-time input.

Figure 85: Material and ambient recording using contact and condenser mics

Spatial sampling uses a 3D scanner (the spatial counterpart to the microphones of sonic sampling) to generate a point cloud by taking millions of point measurements within space. The resulting point cloud provides a high-resolution representation of the actual space and contains the intricate subtleties of texture within the natural world. 3D scanning enables an impressive advancement in an architect's ability to create *as-builts* (building a model from the collected measurements of an existing space). Spatial scanning provides us with an accurate digital model that can be used to understand the existing structure and proportions not as it was drawn to be, but how it exists today. A high-resolution 3D scan can capture the wear marks within the material, the slight differences between one element and another, and the physical artifacts that come with the construction process.

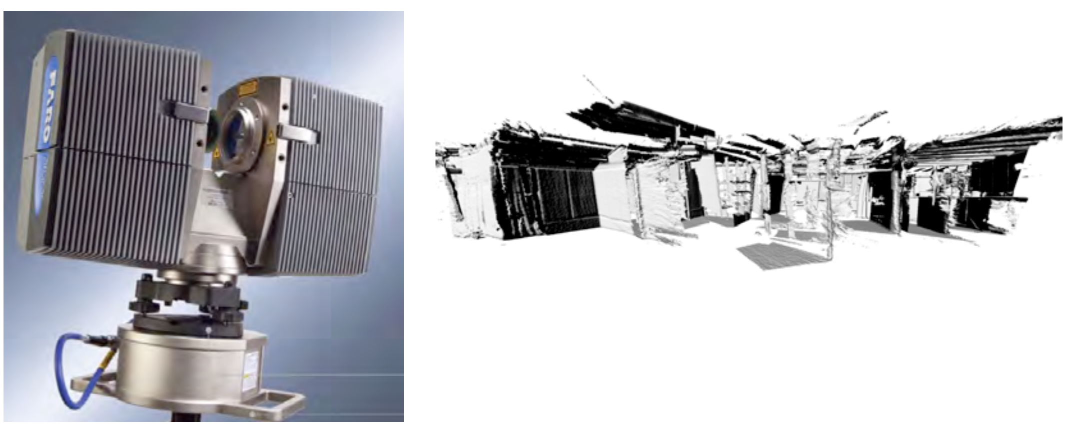

Figure 86: Faro Focus 3D scanner and an example of a 3D point cloud of a house

4.313 Allograms

Allograms enable the digital domains of architecture and music to be united and are achieved by combining the collected spatial and temporal sampling data using the concept of the spectrum as a transformative mediator. Allograms are generated using Kosmos and offer a unique method in the composition of archimusical forms. An *allogram* represents the previously discussed sonic and spatial samples as a spatiotemporal spectrum. Allograms are the main component of Kosmos generated using *MAX MSP*, *Jitter*, *Gen*, and *Python* and are translated into an evolving point cloud and soundscape, whereby the spatiotemporal data can be visualized in real-time and from different spatial perspectives. Allograms developed from an inspiration of the spectrogram because of their ability to visualize multiple parameters of the sonic modality in a matrix form.

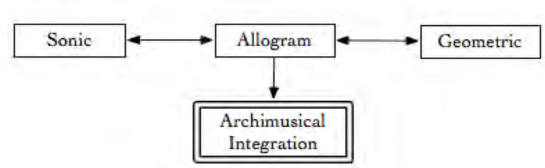

Figure 87: Diagram of the allogram concept

Matrixes serve as an ideal construct for the archimusical mediation. The matrix can be resized, and rows, columns, or planes can be adjusted as needed to allow for multiple dimensions. The spatial and sonic data is encoded into each cell of the respective matrix. This data includes the parameters of the sonic spectrogram (frequency, amplitude, and time) that results from the audio recordings and the coordinate data (X, Y, and Z) of the geometric point cloud which arises from the spatial 3D scan.

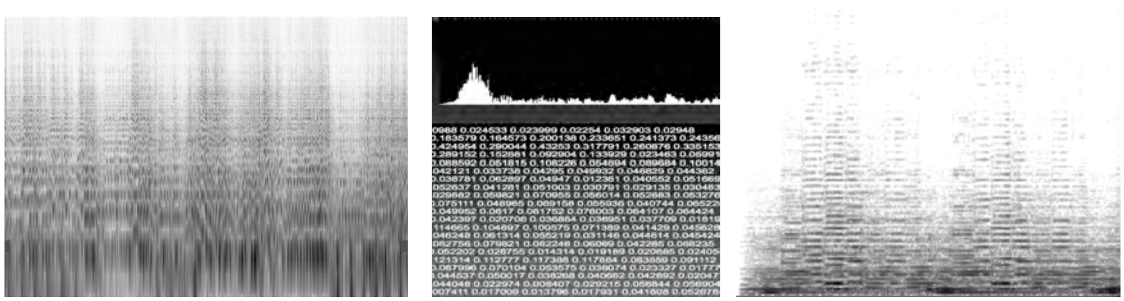

Figure 88: Sonic spectrogram encoded into matrix

Figure 89: Point cloud encoded into matrix

These spatial and sonic matrixes are then combined using matrix transformations, such as *convolution*, *multiplication,* and *addition,* which result in an archimusical unification of the sampled spatial and sonic material. The resulting matrix is spatialized into an evolving point cloud within a spatial environment and sonified into a soundscape, both unfolding in time. When the two modalities are encoded into a representative model with similar data, the values associated with these two modalities can be translated and transformed through each other.

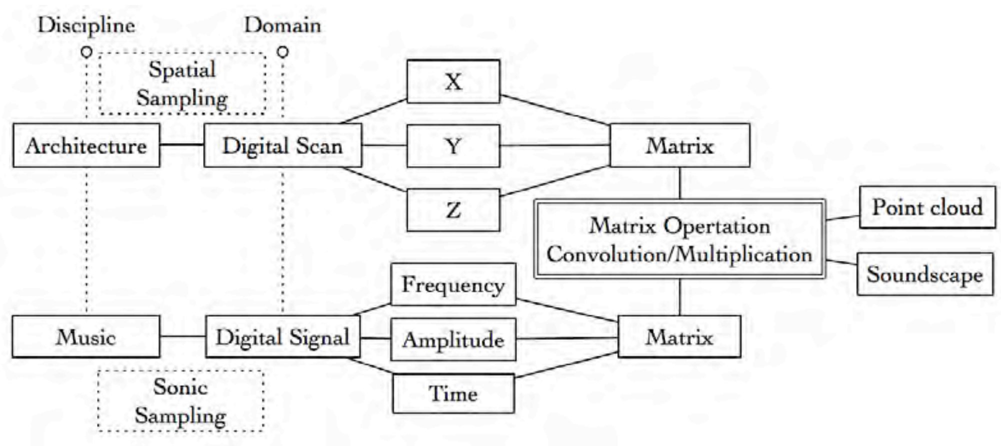

Figure 90: Allogram diagram of matrix unification

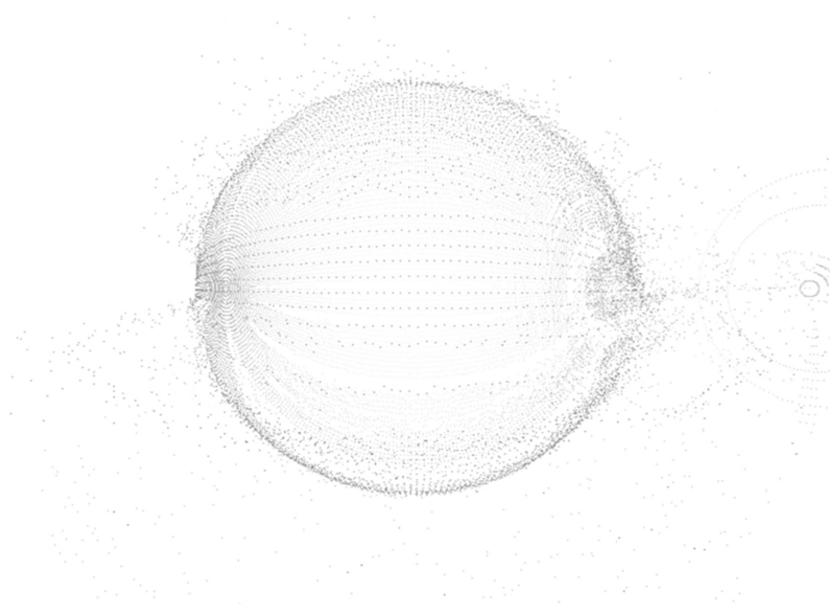

Figure 91: Resulting form of a 3D sphere convolved with sonic recording

Allograms can be used as data sets since each cell of the respective matrix contains information about the spatial and sonic samples from which it is derived. Moreover, this information can be transcribed and parsed into other formats or queried with different data sets, and additional material can be integrated such as spatial orientation data (qW, qX, qY, qZ) or color data (R, G, B). Allograms can be exported as audio for processing using Audio *DAW*'s (Digital Audio Workstations) or as 3D geometry for use with 3D modeling programs.

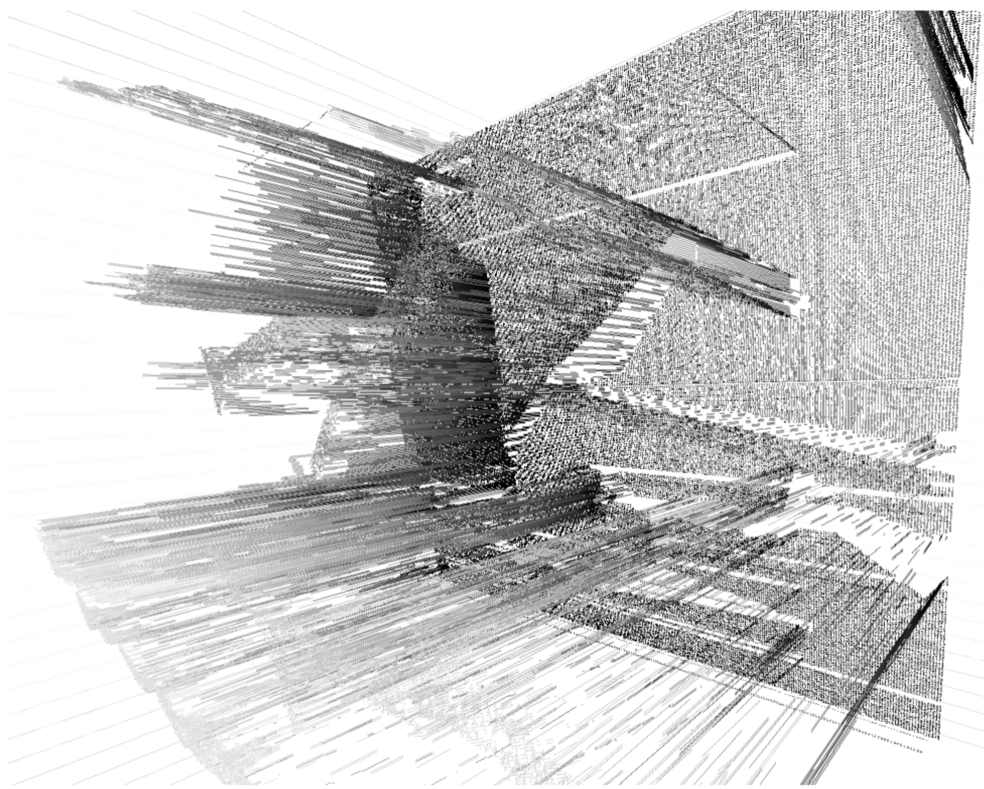

Figure 92: Spatial matrix of a 3D scan study convolved with sonic matrix

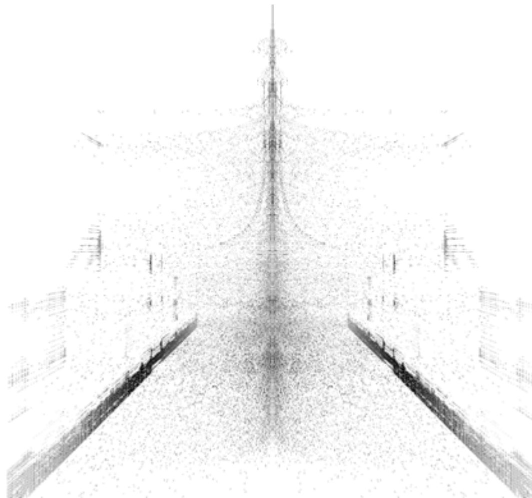

Figure 93: Frozen moment of evolving point cloud in Kosmos

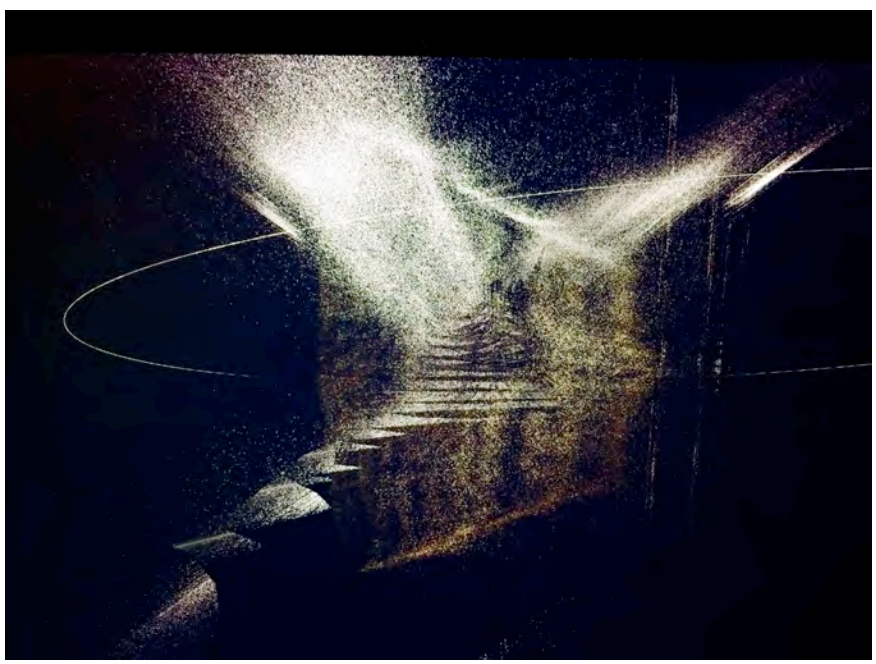

Figure 94: Frozen moment of evolving point cloud in Kosmos

4.32 Computational Framework

Computation has advanced the field of architecture and music in many capacities. In music, computation has been integrated to explore digital synthesis techniques and the compositional development using DAW's (Digital Audio Workstations). Computation has been used to allow the musical modalities to be translated with other disciplines as seen with programs such as *MetaSynth*, *IanniX*, and the *UPIC*. In the architectural discipline, computation has advanced the ways that algorithms are used in generative geometry and parametric design (Jabi, 2013), aiding in translating from the traditional realm of creating architectural drawings that used to be done by hand.

Within the realm of generative, algorithmic, and parametric design, software that emphasize the link to other modalities and disciplines of music and sound are limited. Programs such as *Grasshopper* provide some flexibility when integrating images and data sets, but the modality of sound is rarely included and usually requires additional applications such as *Python*, *Processing*, or *RhinoScript*. Kosmos has been developed to help bridge this gap of trans-disciplinary computational connections in these fields.

Kosmos is built with *MaxMSP*, *Jitter*, *Gen*, and *JavaScript*. These programs were chosen because of their functionality within the audio and visual domain, their ability to work with matrices, and capacity to connect to external hardware. These capabilities enable the digital modalities of architecture and music to be brought into one computational system for new transformational compositions.

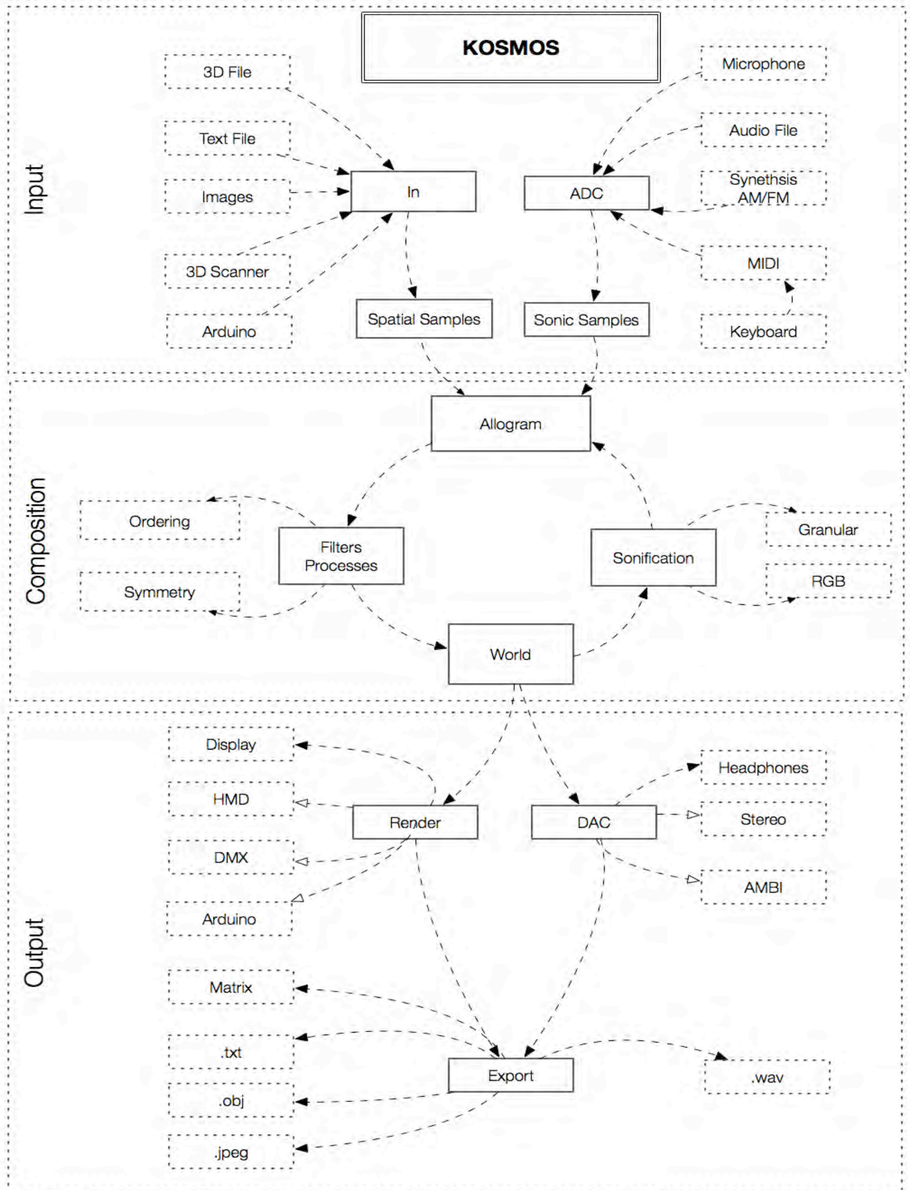

Figure 95: Diagram illustrating the basic structure of Kosmos

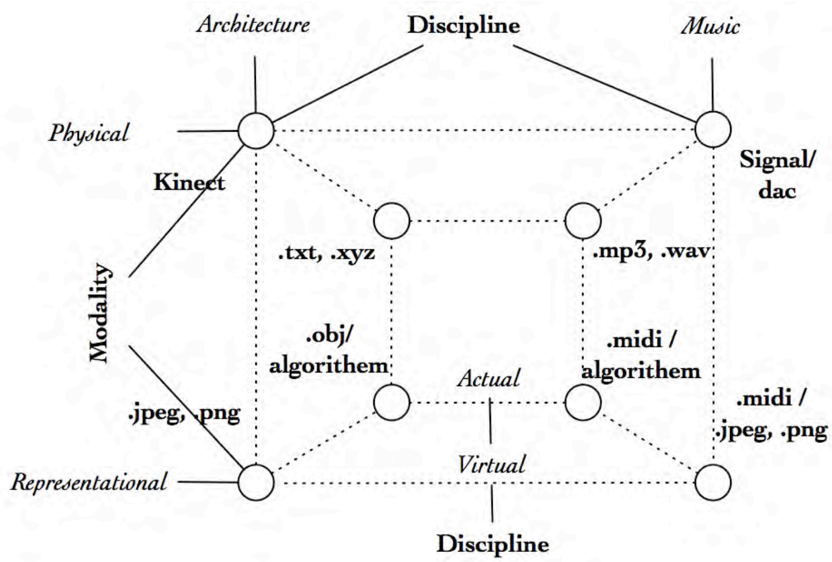

Figure 96: Constellation with corresponding file types used in Kosmos

4.321 Kosmos Interface and Controls

Kosmos is organized as a series of control interfaces including the *Main Control Interface,* the *Render Window*, *Master Render Controls*, *Audio Controls*, *Modal Element Controls*, *Spectrogram / Allogram Display, and the IO Controls.* Next, we introduce and describe these components of Kosmos.

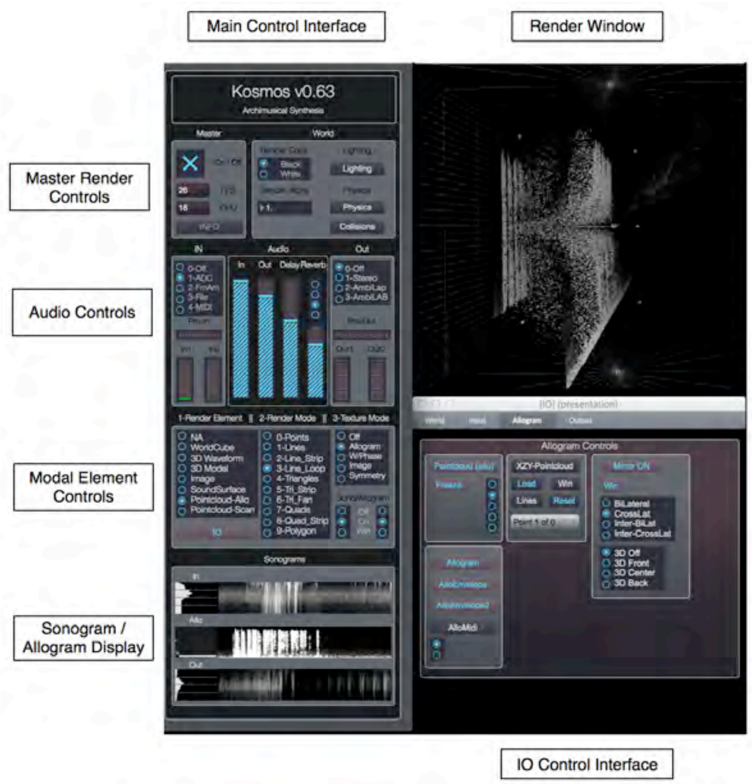

Figure 97: Kosmos interface with description of control components

4.322 Interface and Controls

Kosmos is designed as a spatial and temporal computational world where all interactions occur within a 3D environment. This world is controlled by the *Main Control Interface* and visualized in the *Render Window*. Within this world, specific global parameters can be controlled by the *Master Render Controls* panel including, *Master Render, Lighting, Render Rate, Render Color*. Additionally, the Framerate (*FPS*) and the Central Processing Unit (*CPU*) usage are displayed. There is also an *Info* button which includes instructions for the importing and exporting of specific data types, including which files can be imported and exported, and keyboard shortcuts for commands that enable navigating the program more efficiently.

The *Render Window* is positioned next to the *Main Control Interface* and is where the generated modal elements are rendered and visualized. This environment allows six-degrees of freedom (position and orientation) and is an essential aspect of archimusical synthesis since it exists in both space and time and can be used to navigate with shortcut keys (*up-arrow*, *down-arrow*, *left arrow, right arrow, w, a, d, x)*.

The *Audio Controls* allow adjustment of specific audio parameters including volume for the incoming audio (pre-processed) as well as the outgoing sound (processed). Different input audio sources include Digital Audio Converter (DAC), Frequency Modulation (FM) and Amplitude Modulation (AM) synthesis, recorded file, and midi file. The output audio can be sent as a *stereo* signal if being used on a laptop or conventional audio system, or *spatialized* using a multi-channel setup. The spatial setting of Kosmos uses the *Ambisonics* library developed as part of the *Cosm* package for MaxMSP which enables objects in space to have a sound level which corresponds to their relative distance and location. There are associated level meters for visual feedback of all input and output signals within the audio controls interface.

The *Spectrogram and Allogram Display* presents the spectrograms of the input and output audio and processed allogram. These visualizations can be turned off as well to conserve CPU and framerate or rendered into an external window for increased visibility.

A *Modal Element* is an archimusical component that is rendered in the scene. Each of the modal elements can be rendered in different *Render Modes,* including points, lines, triangles, and quads, and shaded with a *Texture Mode* such as a 2D image of the processed allogram or an imported image from a graphic score or drawing.

4.323 IO Control Interface

The *IO Control Interface* reveals a window with five tabs that are labeled: *World, Input, Allogram, Sonify,* and *Output*. The *World* interface window enables the control of features affecting the entire global scene, while the *Input* interface window allows the selection and control of the imported material. The *Allogram* interface window facilitates the selection and control of the allogram processes, while the *Sonify* interface window enables control of the included sonification methods. Lastly, the *Output* interface window enables the selection, control, and export of the processed material. Together, the *Main Interface Control*, *Render Window*, and *IO control Interfaces* make up the main controls for the generation of unique transmodal integrations within Kosmos.

Figure 98: World Control Window

The *World* interface controls camera selection, render context, and global controls including the *WorldCube* and *SoundCube.* The *WorldCube* is a rendering element that draws a boundary box within the render window and helps with scaling and positioning the modal elements within the environment, while the *SoundCube* illustrates the locations of virtual speakers for use in spatial audio scenarios. *Camera* controls allow for orthogonal presets to be selected (*Top, Bottom, Left, Right, Front,* and *Back*) and can be quickly scanned through by pressing the backslash *("\")* key. The *Render Context* selects which display to render, including the native Kosmos display, Oculus, and HTC VIVE.

The *Input* window of Kosmos includes controls for the material that is imported into Kosmos. The input material is file types that correspond to the modal elements from both architecture and music including content that is both recorded and real-time that comes from the physical domains. Settings relating to the imported material can be controlled including starting and stopping the recorded audio and midi files and enabling rendering of imported images and 3D geometry. Below is a screenshot of the Input window and an AmTM constellation that illustrates the associated file types.

Figure 99: Input Control Window

The input controls enable the modal elements to be imported within the compositional environment of Kosmos. Once within the program, these modal elements become the generative material of archimusic. In the *Allogram window*, there are different controls for visualizing processing the imported material. The first is the *Main Allogram Control* and *Allogram Envelope.* Next are the *AlloWave, AlloSurface*, *AlloField, AlloCloud,* and *Symmetry* options. Each of these parameters enables different transformations of the modal elements.

The parameters of the allogram can be adjusted including scaling the intensities by multiplying the matrix using a logarithmic scale and can be applied to either the frequency or phase data. The *Allogram Envelope* provides a visual display of the envelope of the allogram.

Figure 100: Allogram Control Window

There are three features for direct visualization of the allogram data. The first is the *AlloWave*, a 3D waveform, which renders linearly through time from right to left or as a ring, while the second is the *AlloSurface*, which renders the data as a NURBS (Non-uniform rational basis spline). The *AlloField* is an isosurface, which represents the point cloud as continuous values within the volume of the environment. These visualizations are helpful when real-time visual feedback of an imported modal element is needed.

Once the allogram is generated from the sonic and geometric data, it is visualized in the render window as an AlloCloud which spatializes the point cloud and represents the archimusical form in real-time. As the AlloCloud is being generated, it can be frozen at a particular moment in space and time; then, using navigation controls, we can explore its structure and composition from different perspectives. Render modes and render textures can be applied to further study the possible variations.

Symmetries operations can also be applied. These symmetries can be represented as bilateral, cross-lateral, or interlace in two or three dimensions. Symmetries are useful in amplifying the patterns found within the AlloCloud and aid in establishing spatial order in composing new forms.

The *Sonify* window allows volume control of each of the sonification methods including DAC input, FM/AM synthesis, imported audio files, and MIDI. The allogram can be synthesized into sound using the RGB channels of the texture or image and the XYZ coordinates of the point cloud file. The resulting signal can be sonified using a granular synthesis engine which maps the signal in the space and applies the current camera position within the rendered environment as the current grain that is played. Additionally, normalization and signal limiting can be applied.

Figure 101: Sonify Control Window

The resulting modal transformations can be output or exported from Kosmos. These outputs match the modalities of the inputs and follow the same file formats. The outputs of Kosmos occur in both recorded and real-time and allow for the exporting of data for new material production and the display or performance of the generated material. Within the musical discipline, the generative output [va(M)] can be exported as compressed audio files (.mp3 and .wav). The architectural modalities can be exported in similar ways. Drawings [ar(A)] can be exported as image files (.jpeg and .png), while the generated point cloud [va(A)] can be exported as text files (.txt, and .xyz). 3D models [vr(A)] can be exported as an object model (.obj) file using any of the supplied render modes. The output modalities can be utilized as the standalone material within Kosmos or as material for other programs, such as 3D modeling software or audio synthesis engines. The output material can also be used to input back into Kosmos for additional processing or as a feedback mechanism.

Figure 102: Output Control Window

4.324 Kosmos Examples

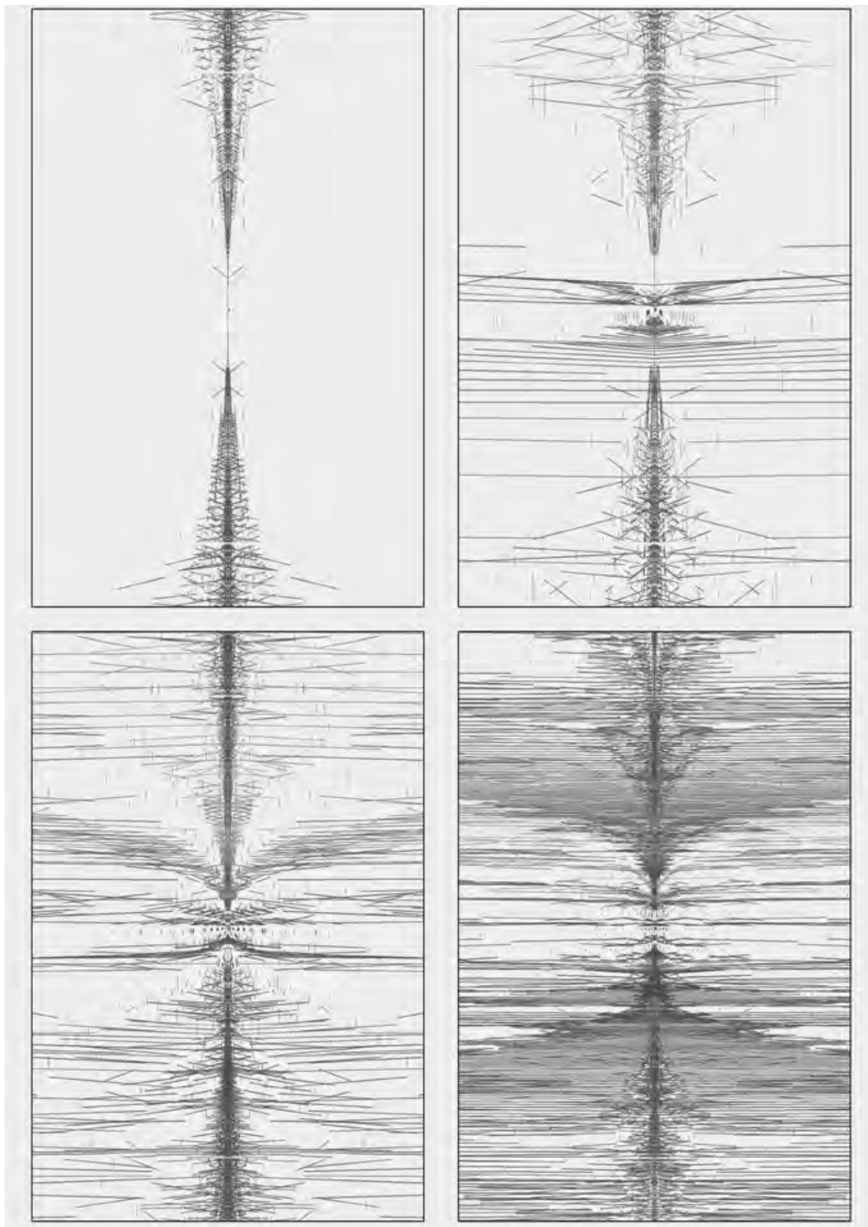

Figure 103: Allogram rendered as four harmonic layers

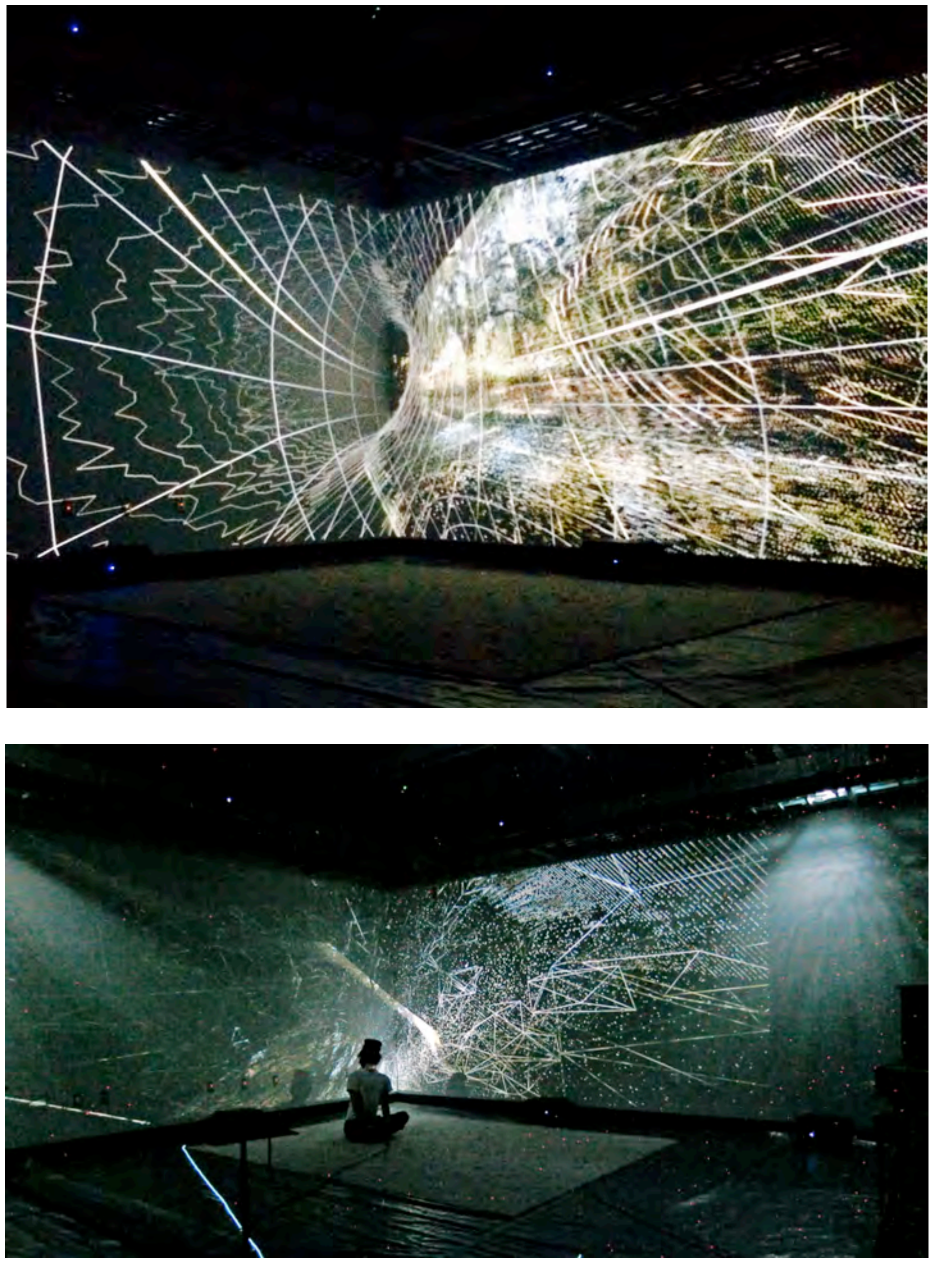

Figure 104: Kosmos in real-time performance w/ 3D sound and projection and user in virtual reality using HTC VIVE

4.33 Summery

The goal of this tool is to enable the transformation of the digital modalities of architecture and music by creating a fluid workflow whereby the materials and processes of these modalities are abstracted and treated as a liquid form, able to exist in all modalities at once. In this section, we have described the computational generative system Kosmos. It has been developed from the ground up with intentions to explore and experiment with the modalities of architecture and music simultaneously. The computational framework, modal elements, layout, and interface of Kosmos have described the methods of this trans-disciplinary tool.

Together, Kosmos and the methods of spatiotemporal sampling and allograms harmonize the unique needs and strengths of both musical and architectural design systems. These enable the composition between architecture and music and lead to compelling new territory that aims to advance the discipline. This territory is explored in the development of proof-of-concept archimusical synthesis studies, which are described in in the next section of this dissertation.

5. Archimusic Synthesis Studies

"Architecture is orchestrated of materials in rhythmic arrangements, proportioned melodically. A more subtle aspect of this analogy occurs in- time. Timbre, spectral distributions and spectral dynamics, constitute the in-time component of music. What is their spatial equivalent?"

~ Marcos Novak (Novak M., 1992)

The *Archimusic Synthesis Studies* will describe a selection of proof of concept projects that have been conducted using the knowledge gained from the Archimusical Transmodal Matrix and Kosmos. The goal of these studies is to experiment with the mentioned modal elements and explore the aesthetic qualities and spectral complexity which arises from the transformation of spatial and sonic data. These projects aim to introduce new directions capable of being examined by using the contributions of this research.

In the following chapter, we describe a selection of projects that fit into three categories. First is the *Initial Studies*, which include some of the first explorations focusing on the translations of basic geometric shapes, sounds, drawings, and spaces using the sonic spectrogram. Next, we will present *Sound Scans*, which concentrate on the transformation of existing architectural spaces and elements by utilizing 3D scanned, point clouds and sonic recordings. Lastly, we will present the *Allotope*, a new archimusical composition that uses the concepts of spatial and sonic sampling to generate an original archimusical work.

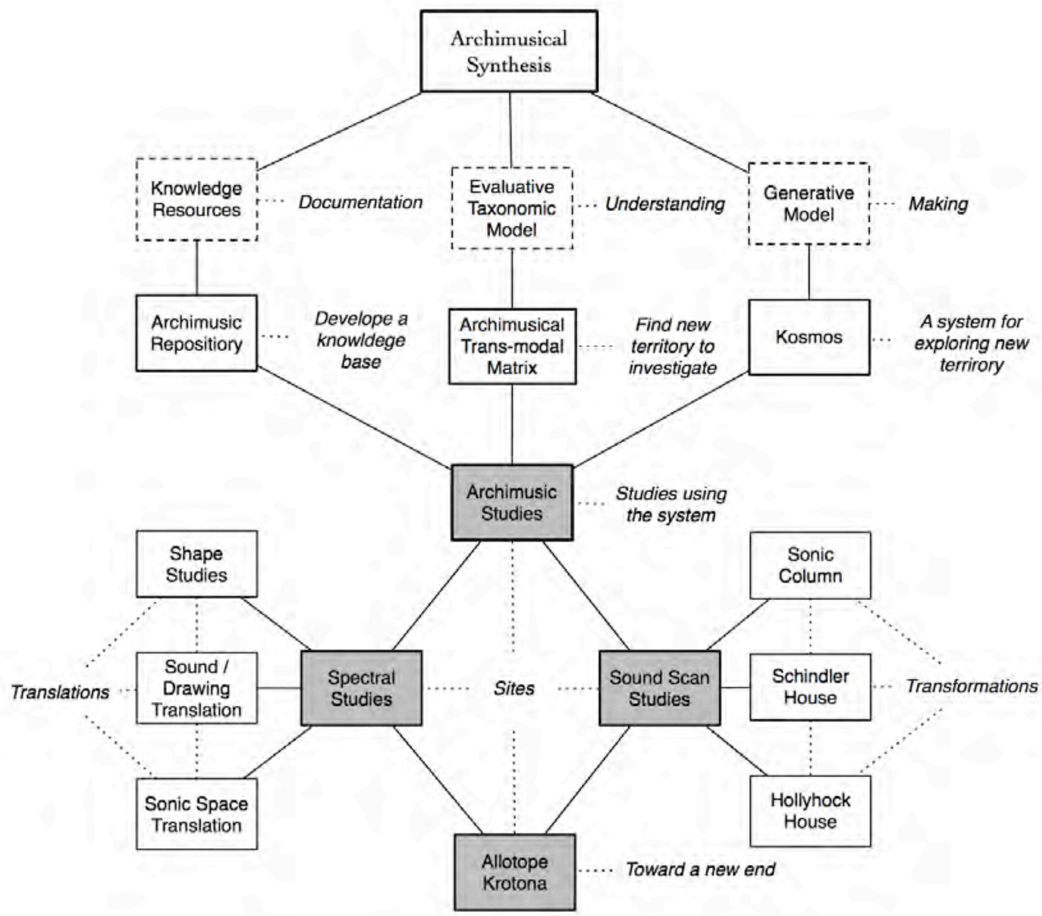

Figure 105: Archimusic research structure diagram

5.1 Initial Studies

Initial Studies were the first studies conducted as part of this research. These studies focus on translational approaches between geometry and sound using the programs Kosmos, Rhino, and Grasshopper. Each of the projects, although brief, are instrumental in the initial stages of this research and explore translating geometric forms, spaces and sounds through different processes and toward different ends. Though the interest of this research focuses on transformational processes, these transformations are comprised of translations. Therefore, it is essential to explore the various parameters of basic translations.

The first study examines shapes and their translations into the sonic medium and the resulting spectrums, followed by translations of sounds, drawings, and spaces. These explore the translation of a digital recording of Bach's *Cello Sonata Suite No. 1*, the transformation of an architectural plan drawing of Palladio's *Villa Rotunda*, and the translation of audio recordings of an architectural space at USC into geometric forms respectively.

5.11 Shape Translation

The shape studies include exploring the translation of two geometric shapes (uniform and abstract) and their associated point clouds into their respective sonic spectrograms, looking at the relationship between the shape and their spectrogram.

The spectrogram is generated by first converting the shape's geometry into a point cloud using Rhinoceros that provides a point at every vertex within the mesh surface of the shape, presenting a good resolution of the original mesh. The point cloud data is converted into a .xyz file containing the coordinates of each point, which is then read sequentially within Kosmos and sonified using a sine wave. This audio is rendered and converted into a spectrogram within Kosmos and then saved as an image file. The shape studies explore basic geometric and sonic translations, starting as a 3D model *[(vr(A)],* translated into audio samples *[vp(M)],* sonified as sound *[pa(M)]*, and converted into a spectrogram *[vr(M)]*.

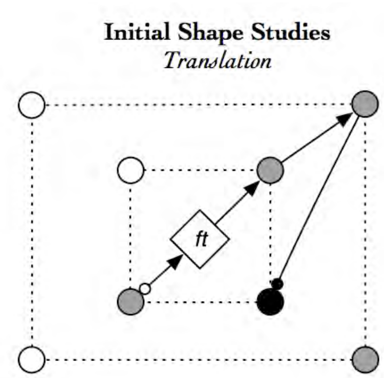

Figure 106: Shape Studies AmTM Constellation

The approach used for the initial shape studies was to move from the simplest to the more complex shapes as a way to move up in dimensions and complexity. This method started with a single point (0D), then moved up to a line (1D), plane (2D), and finally a cube (3D). These elementary shapes failed to produce outcomes of any interest due to the limited amount of data generated by their respective point clouds. Even when the resolution of the mesh was increased, (producing more points), the fact that they were all in the same plane (or planes) made for an underwhelming study.

The next shape studied was a sphere, which was the first form that produced a relevant result. This relevance is due, in part, to the fact that every point is different from the rest, albeit by an equal distance from the radius. This point cloud is sonified and produces the following spectrogram using three sine waves, one for each of the coordinates, X, Y, and Z. For sonification purposes, the subsequent shape studies were all similarly scaled and centered in the (1, 1, 1) octant of the rendered environment, so that all coordinates were in the positive realm. The translation of shapes into geometric forms was carried out in Rhino, while Kosmos was utilized for the data translation and spectrogram processing.

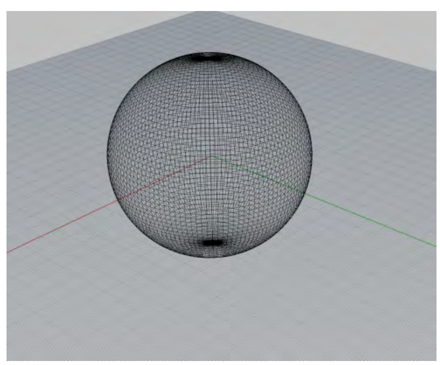

Figure 107: Basic Shape Study 1 – Sphere

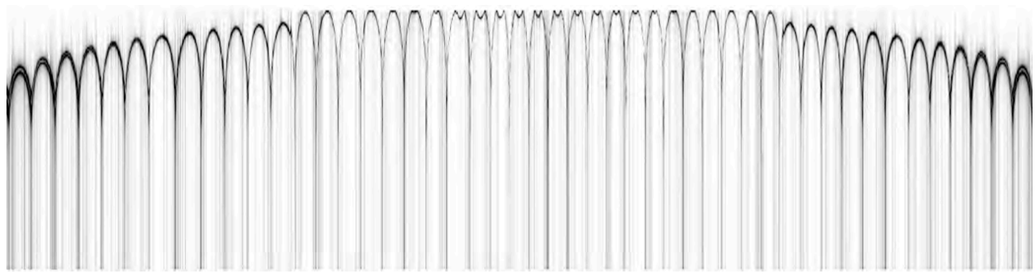

Figure 108: Sphere spectrum sample showing gradual inclination

The regular vertical intervals in the spectrogram are a product of the point's position along the sphere's latitude. As the point's location is read, the angle graduates upward toward the sphere's top pole, and as the data nears the top, the patterns can be seen to reverse as they travel back toward the opposite pole. The inconsistent artifacts observed in the spectra are the result of a few causes. The exported text file formats (.xyz/.txt) occasionally have points saved out of sequence that are insignificant when visualizing the partial data in a 3D modeling program (which render the entire object at once), but become noticeable when generating the form through time as is done in the spectrum. The random peaks seen throughout the spectrum are caused by subtle syncing differences in the envelope ramping, and the dual horizontal bands near the middle of the spectrum are attributed to the normalization process of the data. The parameters of a *running average* algorithm help to correct these artifacts. If we use Frequency Modulation (FM) synthesis, the outcome is more vibrant, and harmonics emerge as seen the following figure.

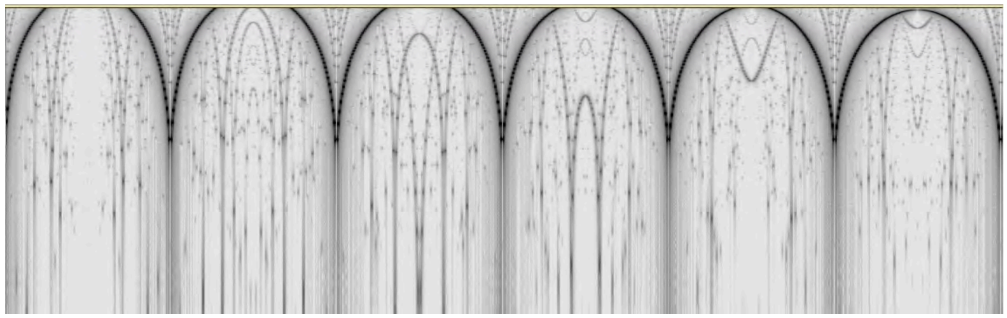

Figure 109: Basic Shape Study 1 - Sphere spectrum

A deformed sphere was used to compare an entirely different shape. The following form and spectrogram were generated, which illustrated the radical changes and fluctuations visible in the geometric shape. The shape was again sonified with a pure sine wave and given its abnormal qualities, it gave rise to an interesting spectral structure when unfolded through time.

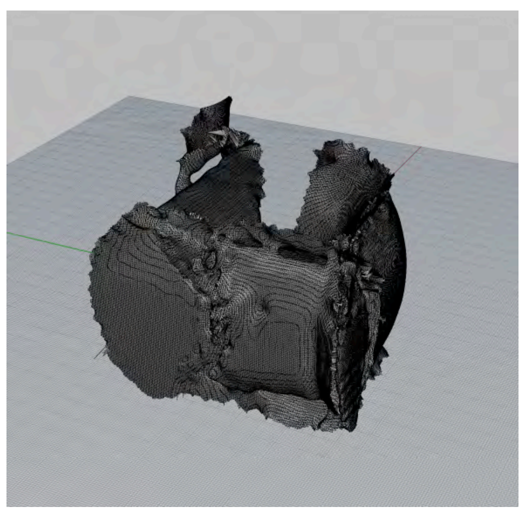

Figure 110: Basic Shape Study 3 - Abstract

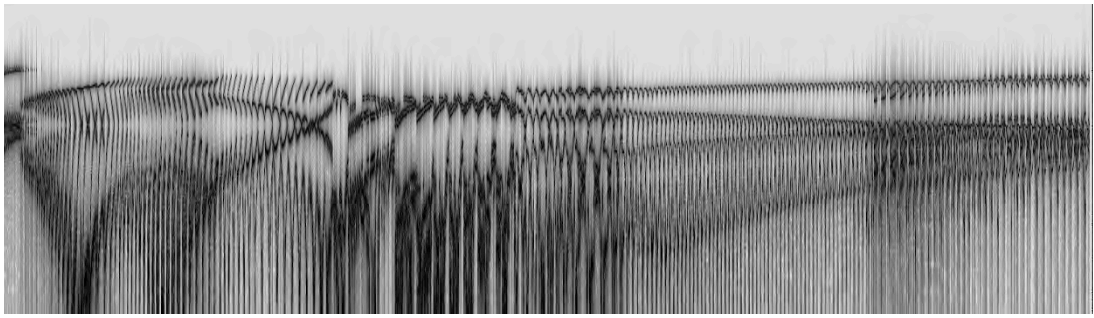

Figure 111: Basic Shape Study 3 – Abstract shape spectrum

5.12 Drawing Translation

The drawing translation study explores the translation of an architectural drawing into a geometric form through sonic modality. Whereas the last sound translation experimented with the geometric structure was generated from a sound file, this study translates a drawing *[pa(A)]* into an audio file *[va(M)]*, followed by translation into a geometric form *[pa(A)]*. Drawing translation explores another transmodal integration, and leads to another step closer to the transformative processes of this research.

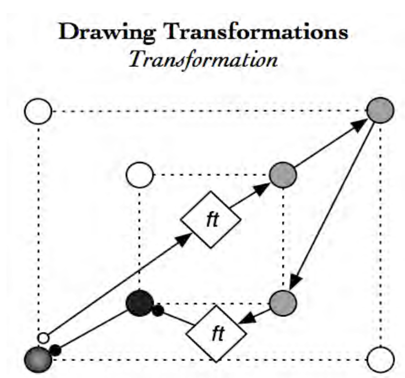

Figure 112: Drawing transformations AmTM constellation

This study begins with the plan drawing of Palladio's *Villa Rotunda* (1571). It was chosen because of Palladio's interest in musical harmonics and the translational studies that were prevalent during the Renaissance period. The translation works by importing the plan drawing as a digital image and encoding the image into a sonic spectrogram using Kosmos. This encoding translates the black color value of the image from left to right, mapping the time along the X-axis and frequency along the Y-axis.

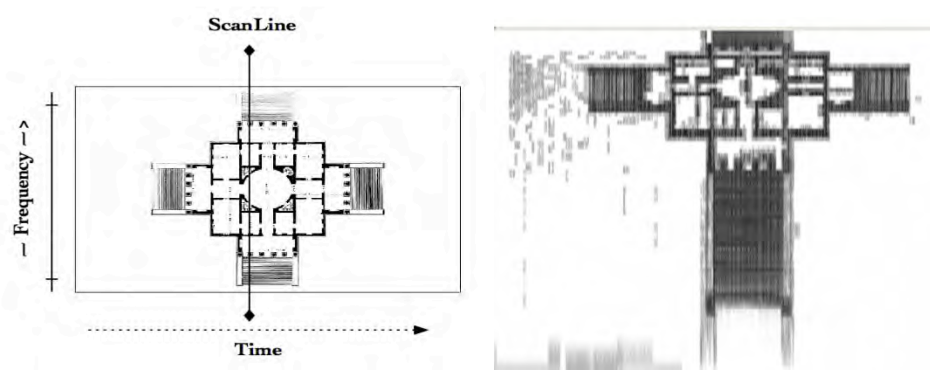

Figure 113: Diagram of mapping plan drawing and resulting spectrum

The sound generated from scanning the architectural drawing produces its unique transmodal relationship, whereby qualities of the drawing's form and structure can be heard in time. The structural relationships are sonified with sine waves. The resulting sonic spectrogram is exported as an image file. Then, while Rhino and Grasshopper are used in the compositional process of the formal geometry, Kosmos is used to create a displacement map similar to the sound translation study.

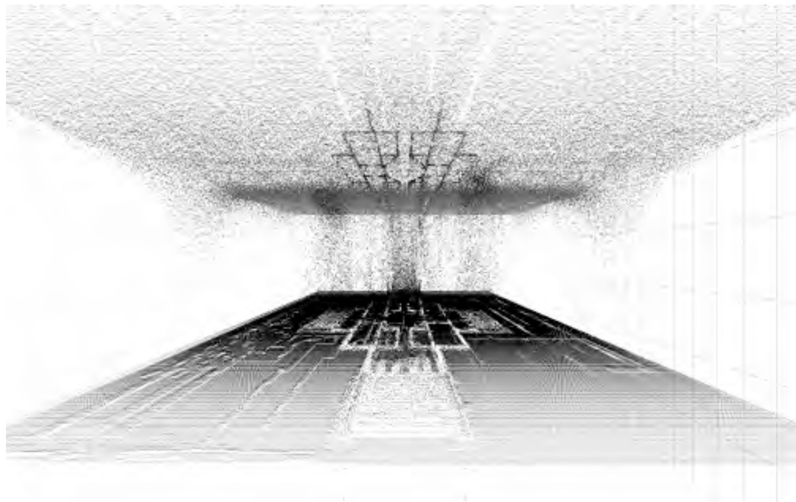

Figure 114: View of point cloud displacement form within Kosmos

The displacement mapped form is exported to Rhino to generate the drawings. Symmetry operations are applied to the resulting geometric form to develop a structure with a compositional feel similar to the design approach of the Villa Rotunda, which used a robust cross-lateral symmetry. The archimusical forms that resulted from this study illustrate organizational similarities to the plan of the Villa Rotunda. The symmetry operations are partly responsible for this analogy. Although from distinctly different processes, the proportions of the resulting form and the proportions of the Villa's elevation have a similar harmonic structure. A future study might also incorporate elevation and section drawings of the structure to produce unique three-dimensional spectral assemblage from different perspectives.

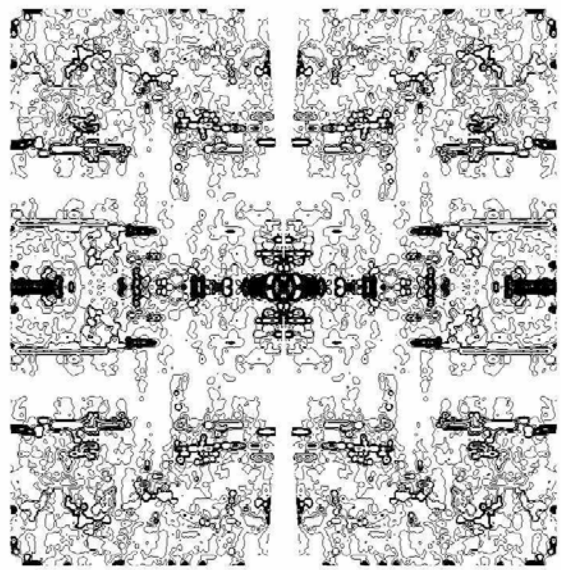

Figure 115: Archimusical drawing with same symmetry as the Villa Rotunda

5.13 Sound Translation

The sound translation study explores the translation of a digital recording of a musical work into a geometric form. The *Prelude* from Johann Sebastian Bach's *Cello Suite No. 1 in G Major* was used for the original sonic material. It was chosen because of its relationship with the translational studies that were prevalent during the Baroque period, and Bach's mastery of the tonal system, fugues, and virtuoso instrumentation.

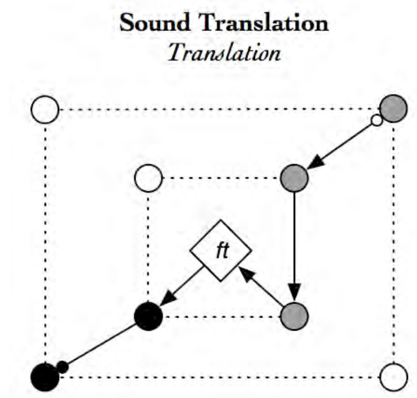

Figure 116: Sound Translation AmTM Constellation

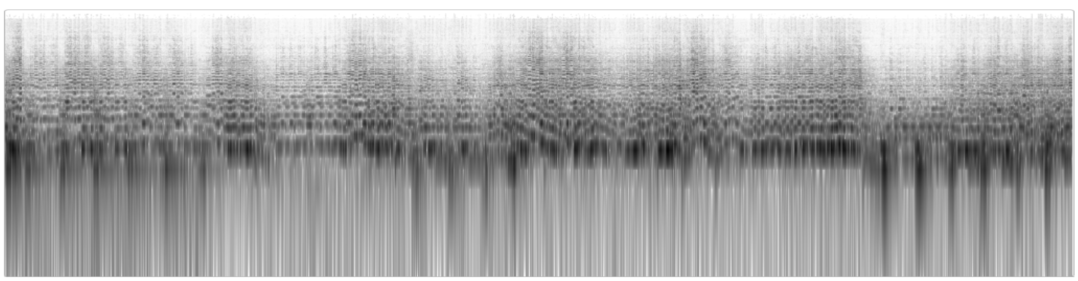

Figure 117: Spectral Sample of Cello Sonata by Bach

The process began by importing a digital audio file *[va(M)]* and generating a spectrogram using Kosmos. The spectrogram was then converted into a geometric point cloud *[va(A)]* by mapping the X and Y dimension to frequency and time respectively. The amplitude of each frequency was mapped to the height of the geometry in the Z dimension, giving the point cloud three-dimensional depth, similar to *heightfield* or *displacement mapping*. The point cloud was then rationalized and converted into 3D geometry *[(va(A)]* and drawings *[pr(A)]*.

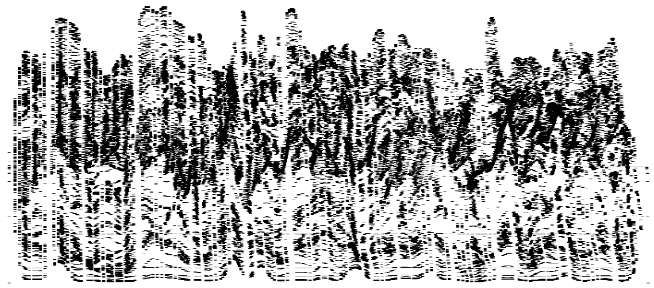

Figure 118: Generated Point Cloud

The forms that came about due to this process were exported and brought into Rhino to be rationalized and converted into the drawings below. The resulting shapes created a geometric component akin to a sonic motif. These geometric motifs were further composed using bilateral symmetry to develop a structure with a compositional aesthetic similar to the Baroque cathedrals.

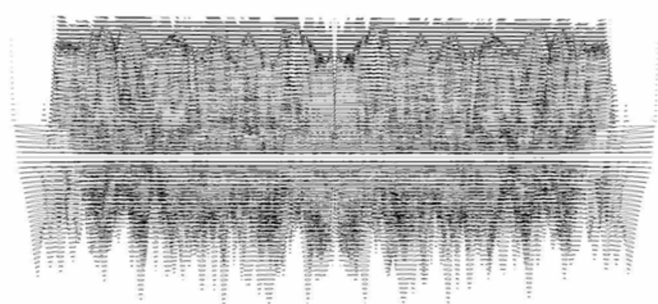

Figure 119: Symmetry operation and resulting spectral form - Elevation view

The resulting geometry embodies the spectral qualities heard in the original piece of music, revealing synchronizing relationships when viewed and heard together. Simultaneously exploring the form while listening to a musical work is a complete experience, and allows the transmodal relationships to grow and become more evident. Future generations of musical forms could be experienced as an immersive installation. It would not only offer a unique experience for the user, but also prove to be a robust compositional tool for the architect/composer.

5.14 Sonic Space Translation

Sonic Space study explores the translation of live sound recordings into geometric forms. It was conducted at the 2014 ACADIA (Association for Computer-Aided Design in Architecture) Conference Hackathon held at the University of Southern California. The theme of the event was *Digital Agency*, and was sponsored by the USC Annenberg Innovation Lab and Unity3D. At the day-long Hackathon, students and researchers were invited to join teams that focused on a range of new design techniques. This project introduced the team members, including Ioanna Georgitsopoulou, Erin Lani, Tatjana Polyakova and Eddie Winn to the concept of archimusic and the techniques to explore it.

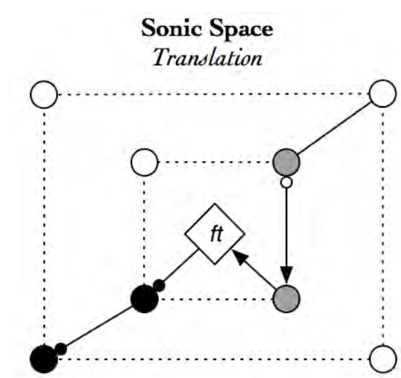

Figure 120: Sonic Space AmTM Constellation

The Sonic Space study generated new spatial forms by modeling geometry from sounds heard throughout the ACADIA conference room, focusing on the spectral qualities of the recorded sounds similar to the previous sound study and the location of each recording. Each team member recorded sounds of the physical structure and different materials found throughout the space mapping the location of where each sound recording took place. The process of this study began with recorded sounds [pv(M)], generating the spectrograms of the recorded files [vr(M)], which are translated into geometry [vr(A)], and exporting the geometry for the production of drawings [pr(A)].

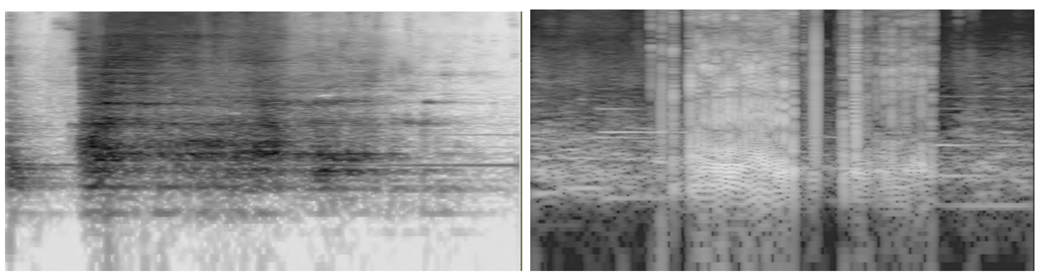

Figure 121: Sonic Space spectrums from recorded sounds.

The following images illustrate different geometries from the same audio samples using different processes and programs. The first image was generated using a displacement map from an image of the spectrogram in Rhino and Grasshopper. The second was constructed by triangulating the point cloud vertex data in *Cheetah 3D*, while the last image was generated using matrix projection in *3D Coat*.

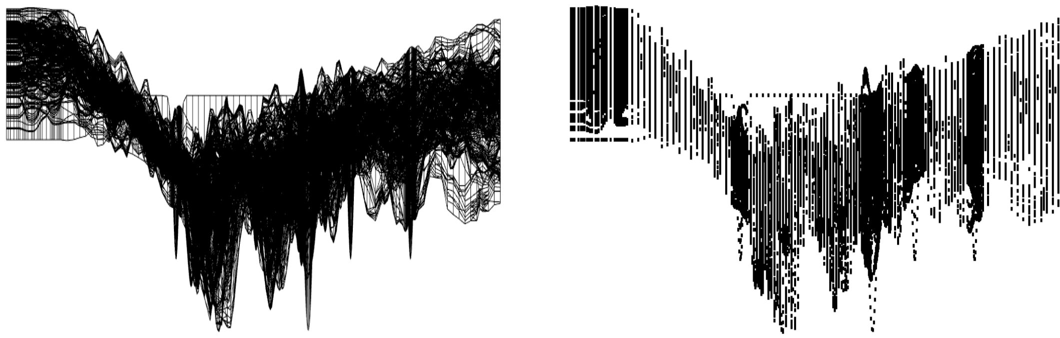

Figure 122: Method 1 - Displacement map using Rhino and Grasshopper

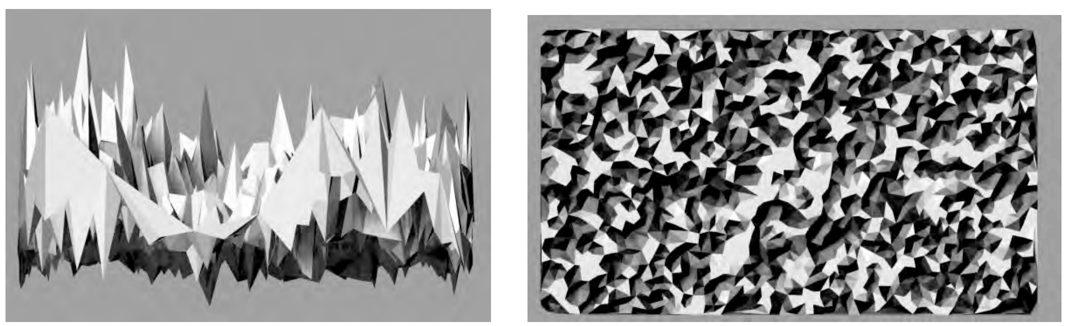

Figure 123: Method 3 – Point cloud vertex triangulation using Cheetah3D

Figure 124: Method 4 - Matrix projection using 3D Coat

Once the 3D models were generated from the audio recordings, the forms were imported back into Kosmos to be experienced in a navigable 3D environment. Each archimusical form was positioned spatially relative to their recorded origin sonically revealing itself as one comes closer. The form was also made to vibrate with the intensity of the amplitude of its respective geometry, giving a dynamic life to the shape in addition to its geometric shape and spatial sound.

This study created a full circle, beginning with recorded sounds from an architectural space. These spatial sounds were translated into geometric forms and placed back into an interactive 3D environment to be experienced as space, shape, and sound. Finally, drawings and a soundscape were made from the different rendered geometry and recorded audio, representing the sonic space as a static drawing and dynamic aural composition.

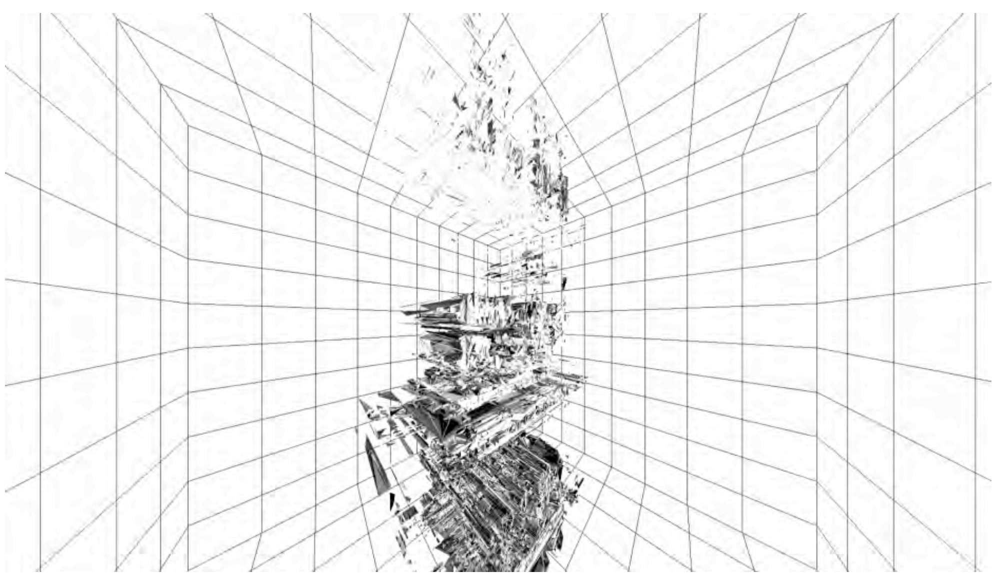

Figure 125: Sonic Space study in Navigable 3D environment of Kosmos

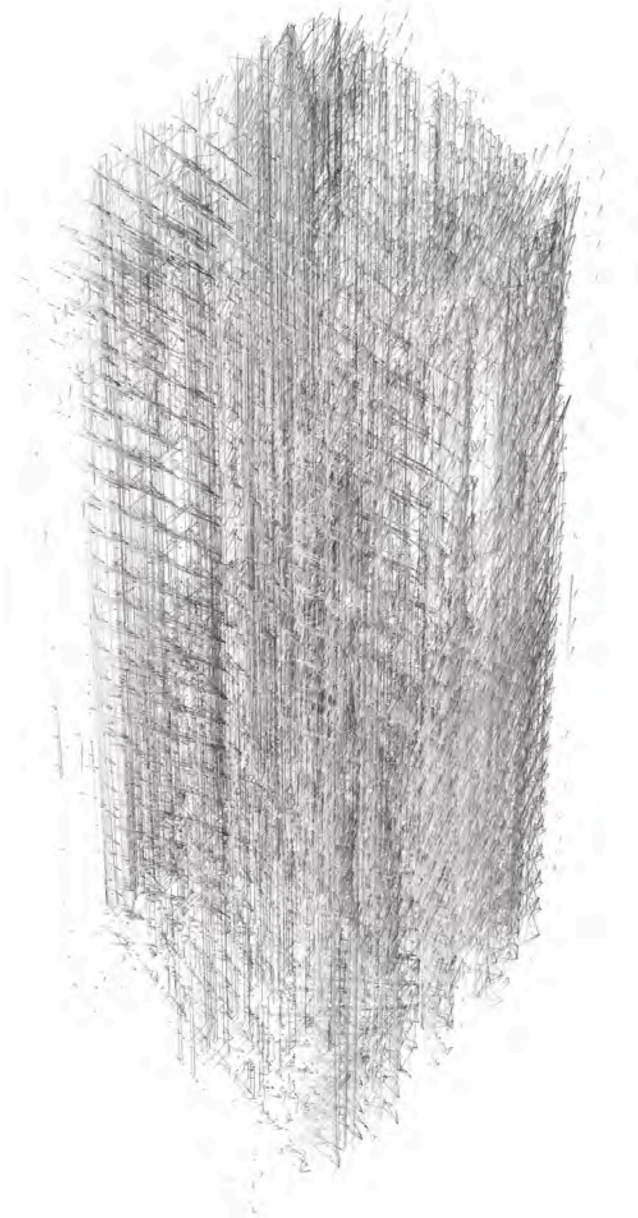

Figure 126: Drawing of the Sonic Space study

5.16 Initial Studies Conclusion

The Initial Studies presented in the last few sections have illustrated the translation of different modal elements including shapes, drawings, sounds, and spaces. These translational studies were conducted as part of the initial research, each focusing on translating a specific modality using the spectrogram as a transformative mediator. These initial studies proved to be formative in the programming and development phase of Kosmos.

The first study examined the representative spectrogram that resulted from translating the point cloud of two geometric shapes, while the second study examined how to translate drawings through the modality of sound. The third study explored translating digital audio files into an archimusical medium, and the last study examined how to translate recorded sonic material from a spatial environment into the archimusical material. The final study also explored bringing the archimusical material into the virtual realm of the 3D environment. Together, these studies illustrate an initial exploration and practical development of multimodal methods that are essential to the transmodal effort.

In the next section, we will explore the Sound Scans. These studies will focus on the transformative methods and approaches of existing architectural spaces and elements using Kosmos.

5.2 Sound Scans

Sound Scans are a series of projects that continue the multimodal exploration using existing architectural buildings and forms. These projects utilize multiple translational techniques found in the initial studies to experiment with the making of archimusical transformations by utilizing spatial and sonic sampling, including 3D scanning and audio recordings.

The first sound scan project, *Sound and the Schindler House*, explores how sound could be incorporated into the processes of reimagining an architectural space. This is achieved by taking sonic recordings from throughout the house and then combining them with 3D point clouds. The following sound scan project, *Les Colonnes Sonores* (The Sonic Column), looks at a singular architectural element as opposed to the spatial area that the Schindler House has explored. The final sound scan project, *Sound and the Hollyhock House*, again explores an architectural space with additional techniques including photogrammetry.

5.21 Sound and the Schindler House

Sound and the Schindler House describes an experiment where the spaces of Rudolph M. Schindler's Kings Road House (also known as the Schindler Chace House or the Schindler House) are transformed using the modality of sound. This project outlines a method for the multimodal integration of architecture and sound, focusing on the ability to re-imagine new ways for sound and architecture to interact throughout the unique context of the Schindler House.

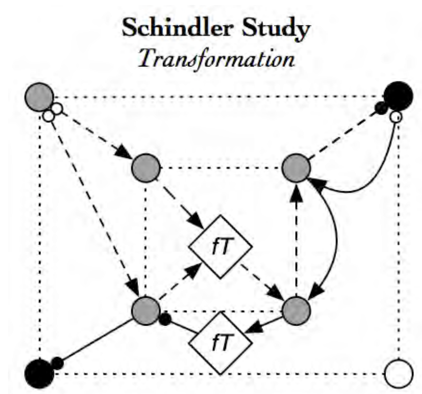

Figure 127: Sound and the Schindler House AmTM Constellation

This project grew out of an invited proposal by the Mak Center for Art and Architecture, Los Angeles in 2012, to consider how to reimagine the Schindler House. The House is a work of architecture of deliberate finesse. Inspired by the natural settings of the Yosemite National Park, it features a dialog between scale, material, and poetic character of the surrounding environment. Within the walls of the house, one is never far from the presence of nature, and within its peaceful surroundings, one becomes more aware of the sounds of the place – both nature and architecture in tune with one another. Allowing the sonic character that already resides throughout the house, this project brings new attention to the spirit of the house. Using archimusical concepts and Kosmos, we can fuse the spatial and sonic relationships of the Schindler House as we learn to listen to architecture.

Figure 128: The Schindler House – Photo by Joshua White

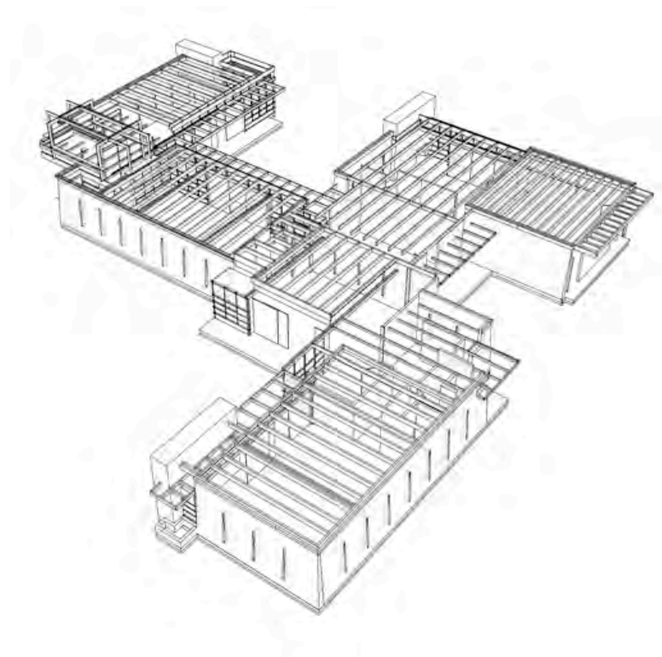

Figure 129: 3D model of the Schindler House – Model by the author

The intersection between architecture and sound is the canvas to reimagine the house through an archimusical perspective. Sound and silence, texture and color, frequency and amplitude are the aspects to experience this new space. Between the grass and gardens lay the building materials of concrete, wood, and glass. These elements serve as mediators embracing Schindler's "*Space as raw material*," creating a transformative and evolving "*architecture for the senses*" (Sarnitz, 1988). Embracing an archimusical approach, we can explore the house as a series of drawings and soundscape that offers a fluid experience that can be heard as well as seen.

The multimodal integration of sound and architecture in this project combines sonic and spatial data sampled from the house. Sonic sampling incorporates recording the interior and exterior spaces. Contact microphones were used for material sampling while condenser microphones were used for recording the ambient environment. Sounds from the surrounding natural environment (grass, trees, bamboo, ambient outside atmosphere) and the sounds obtained throughout the materiality of the House (wood, glass, concrete, copper, ambient inside atmosphere) provide the sonic source material. Though never realized, the composed soundscape was designed to distribute through twelve speakers arranged throughout the Schindler House – eight inside (two within each studio space) and four outside (two in the front and two in the back gardens), giving each room a unique and dynamic composition. This strategy opens the possibility of using sound to inform the generation of new arrangements using sonic recordings and 3d scans of the spaces.

Figure 130: Images of recording the materials of the Schindler House

Spatial sampling is done by 3D scanning the house using a Microsoft Kinect. The Kinect is a camera that uses *structured-light* to collect spatial information in 3D. Though having low resolution compared to a *LiDAR* scanner, this device worked well to record the 3D form of the house. The interior of each room of the house are scanned and saved. These scans were brought into Rhino and composited with the 3D model of the house (Figure 129) built from the original architectural drawings to ensure the scale and proportion are correct. The point clouds are composited together and imported into the MeshLab for cleaning, while Rhino is used to align the scanned segments. The final point cloud is imported into Kosmos and combined with the sonic material in the generation of the allogram.

Figure 131: 3D scanned point cloud of the Schindler House

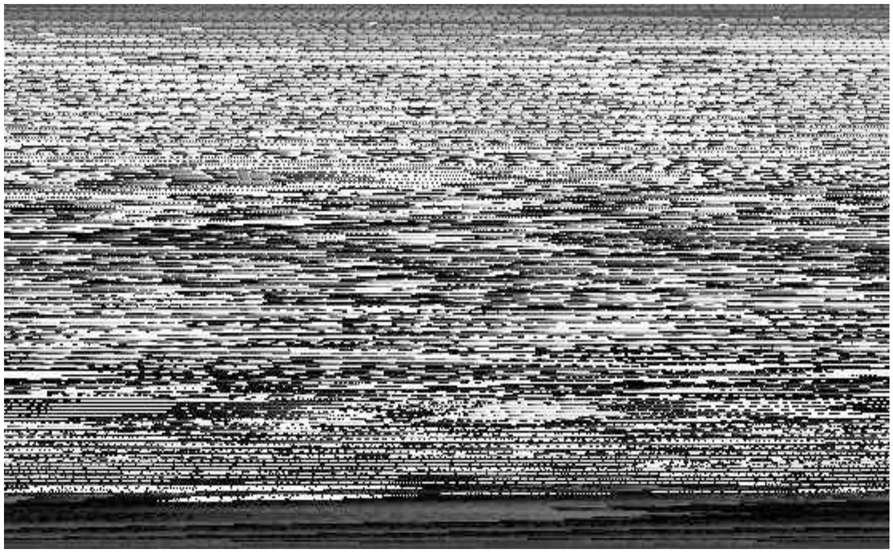

Figure 132: Allogram screenshot from the Schindler House

Each room of the house has a corresponding allogram which fuses the associated spatial and sonic data of that sample space. These spaces are loaded into Kosmos and sonified into soundscapes by combining the point cloud with the collected sonic samples and spatialized into evolving geometry by modulating the point cloud with the sonic recordings. During the process, certain moments are frozen and exported as sound files (.wav) and geometric files (.obj) to produce a series of artworks that illustrate the archimusical forms. These artworks include a set of archimusical drawings, which illustrate these frozen moments as geometric proportions, while the sampled sonic material is heard as a layered textural soundscape unfolding through time.

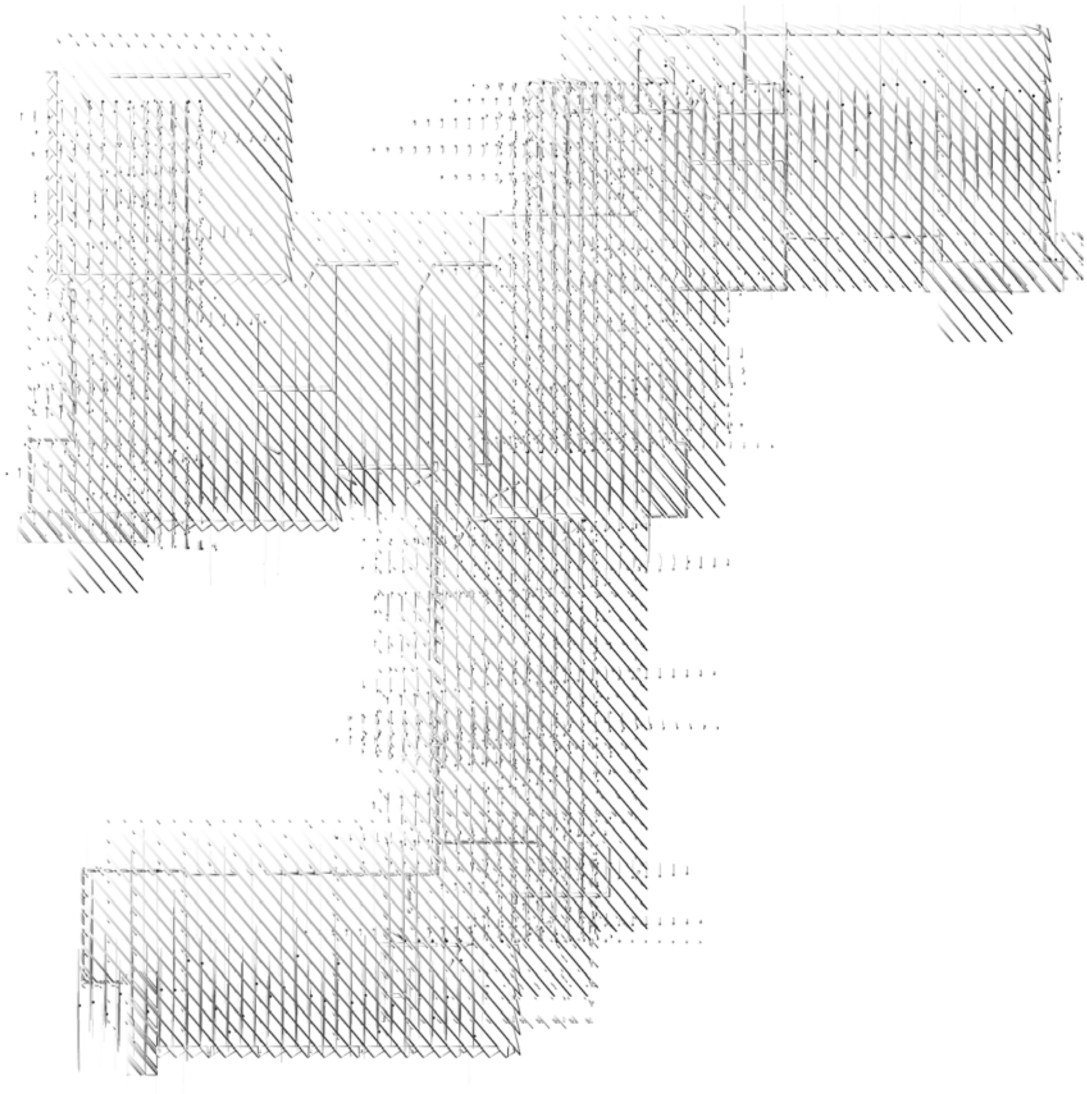

Figure 133: Archimusic plan drawing made by modulating the point cloud with sonic recordings

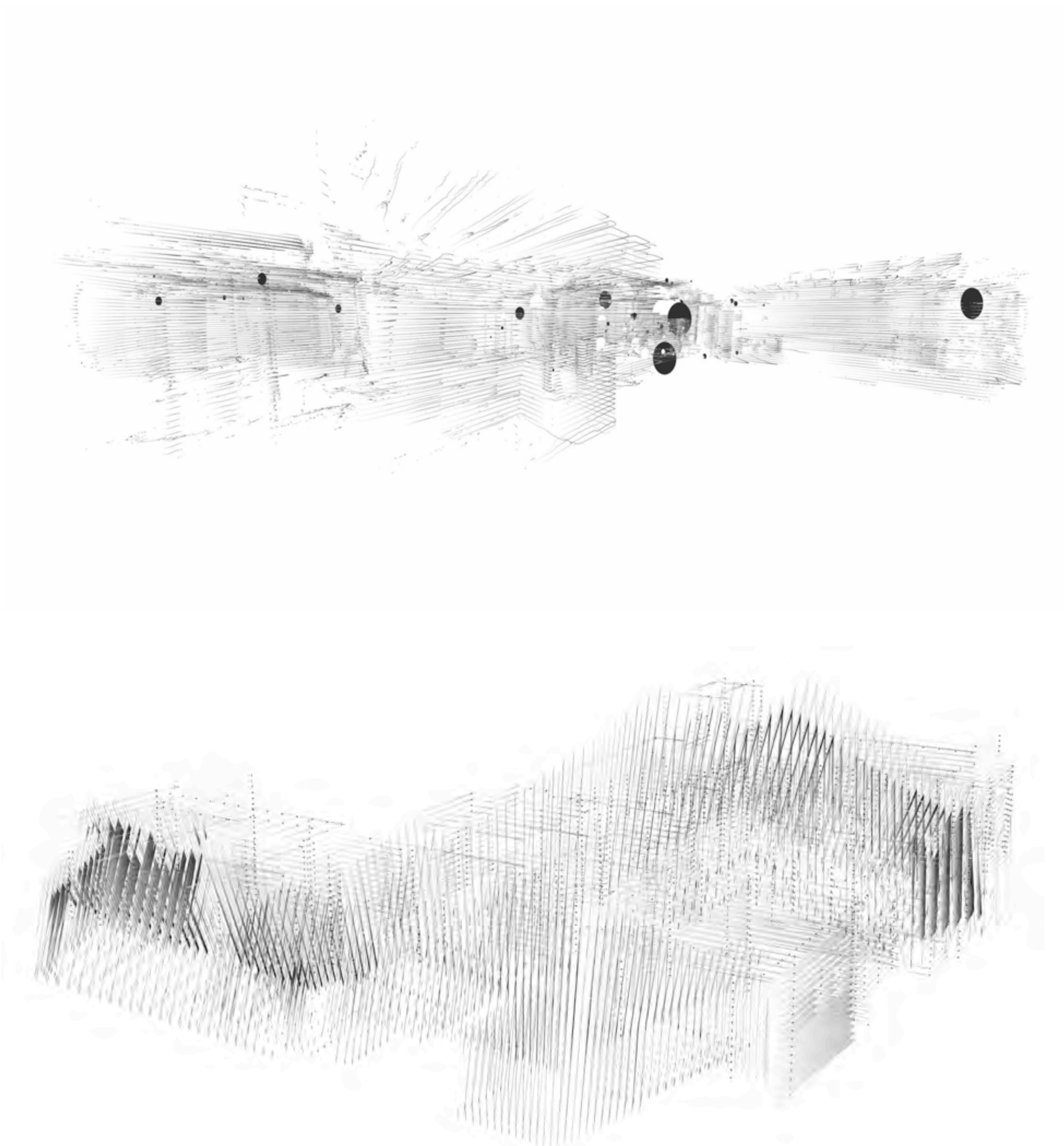

Figure 134: Archimusic perspective drawings of the Schindler House

Figure 135: Sound and the Schindler House at Open Sources in Santa Barbara

The Sound and the Schindler House project has been exhibited at the Mak Center for Art and Architecture's *SchindlerLAB* (Sciotto, 2015) in Los Angeles in March 2015 and the ACADIA 2014 conference titled *Digital Agency* at the University of Southern California School of Architecture in October 2014. Sound and the Schindler House was also a part of the Media Arts and Technology's End of the Year show titled *Open Sources* at UCSB in June 2015.

The full set of drawings and soundscape is located in the following website: https://www.fmyles.com/works/#/schindler/

5.22 Les Colonnes Sonores

Les Colonnes Sonores (The Sonic Columns) is a study that investigates the qualities of an architectural element rather than a structural space as in the Schindler House project. The study takes its name and inspiration from Bernhard Leitner's project *Le Cylindre Sonore*. This project expands archimusical exploration by transforming the 3D scanned proportions of a classical Greek Corinthian column into a sonic modality and back into a geometric archimusical form.

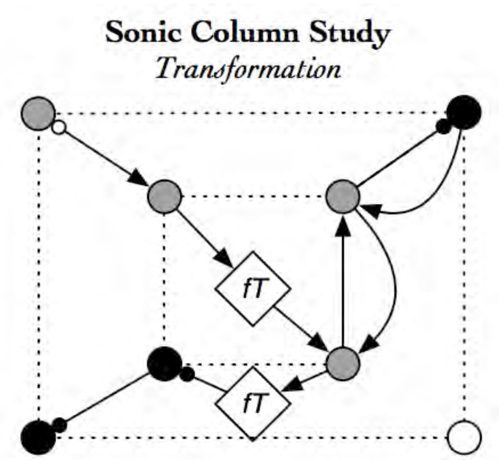

Figure 136: AmTM Constellation of Les Colonnes Sonores

Harmonics is a common term in the discipline of music, and its parallel in the discipline of architecture is proportion. As sounds can be both composed and analyzed regarding their harmonics and partials, architectural forms can be designed and described regarding their proportions. Together, harmonics and proportion refer to the qualities of sonic and sculptural compositions.

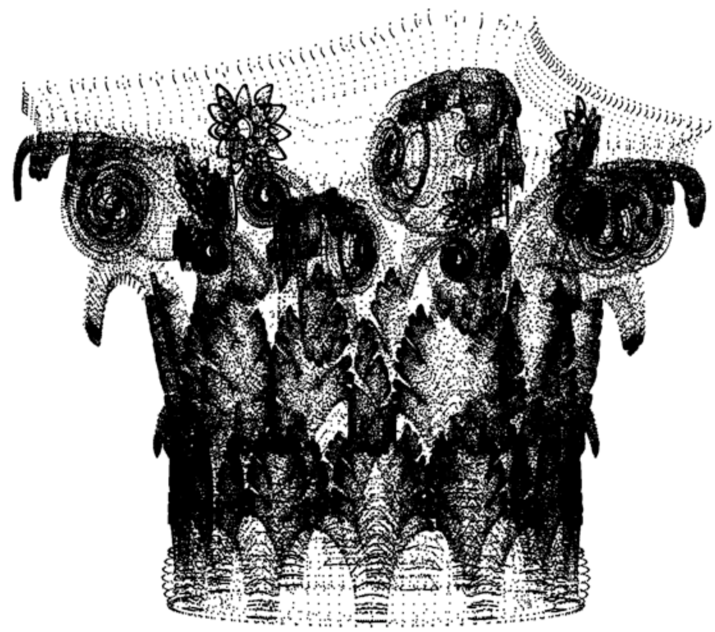

Figure: Processed point cloud of the Corinthian column capital

This project explores integrating the proportions of a classical Greek Corinthian order – that is understood to be the most ornate of the three Greek orders (Doric, Ionic, and Corinthian) – into a sonic modality and explores the spatial relationships of the Corinthian order using sound rather than a purely geometric relation. The architectural and geometric process integrates the modality of sound by translating the 3D spatial position data (X, Y, Z) from the Corinthian column point cloud into corresponding sound data (frequency and amplitude of a sine wave) within Kosmos. An allogram combines the sonic and spatial data, which is synthesized into a new spatial point cloud and corresponding soundscape.

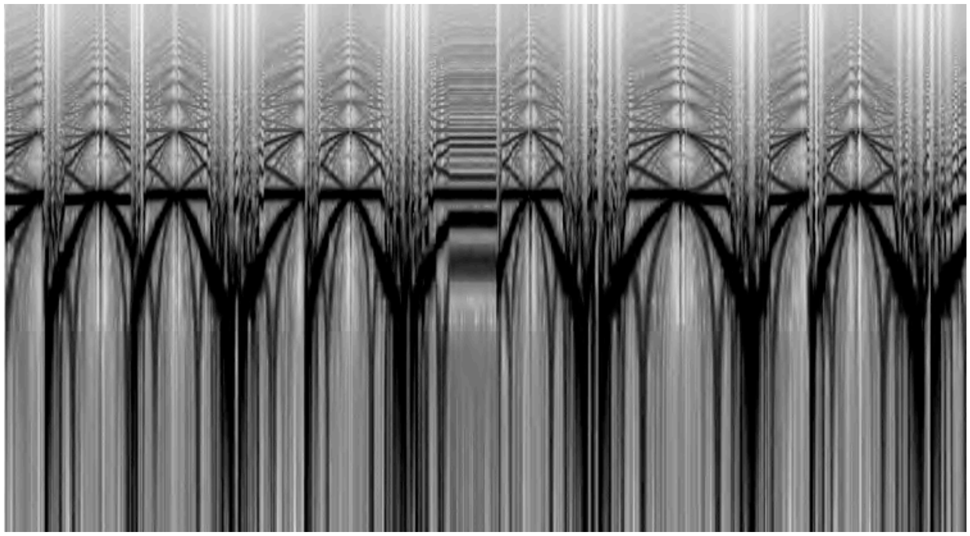

Figure 137: Allogram screenshot from Les Colonnes Sonores

During the process, certain moments are frozen and exported as sound files (.wav), and geometric files (.obj) to produce a series of drawings and soundscapes that illustrate the resulting archimusical forms. These archimusical drawings illustrate the frozen moments as geometric proportions, while the sample material unfolding through time is audible as a layered textural soundscape. Embedded in the resulting geometric drawings is a sonic quality not present in the original built form, illustrating a formal modulation of the initial point cloud using the sonic elements, while the soundscape allows the trans-disciplinary sonification of the column's proportions to be audible.

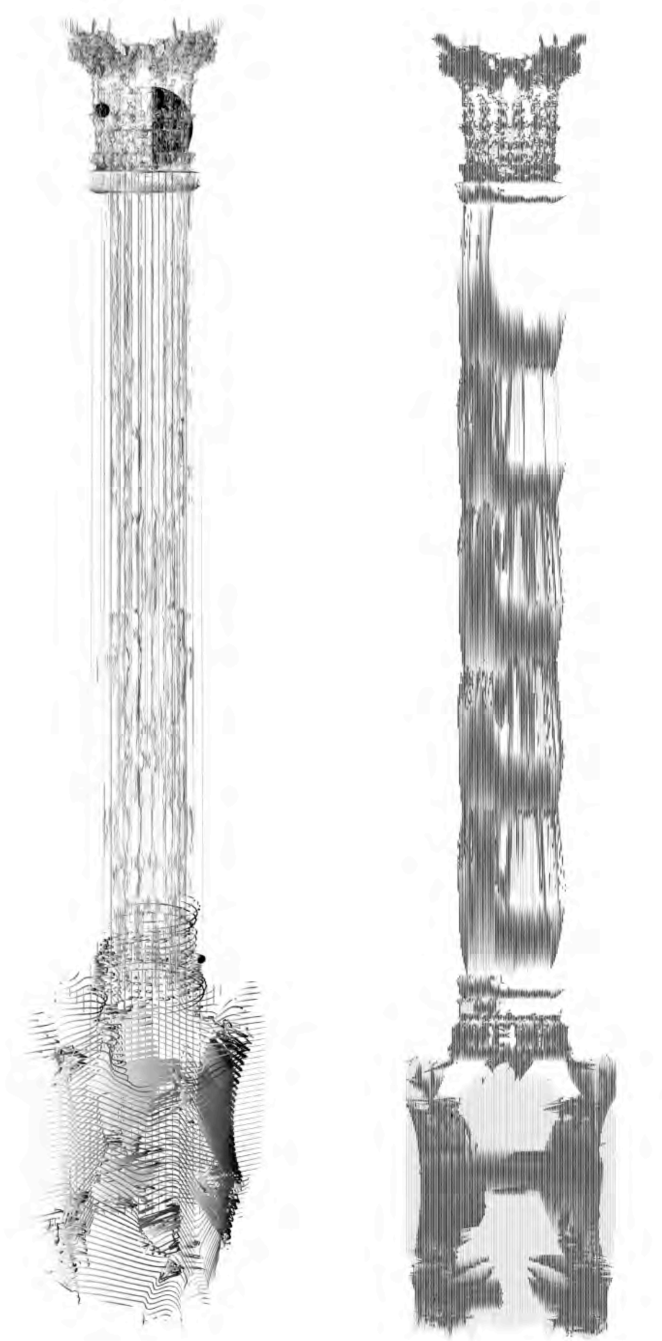

Figure 138: Archimusical elevation drawings of Les Colonnes Sonores

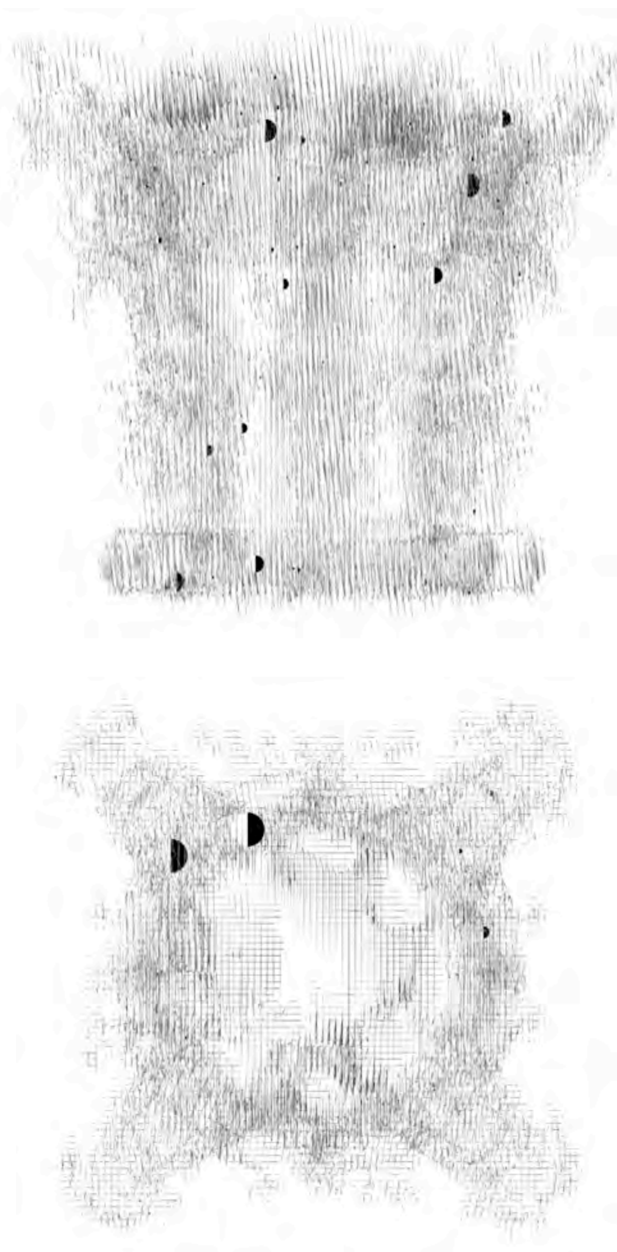

Figure 139: Archimusical drawing of Les Colonnes Sonores capital

Les Colonnes Sonores was exhibited as part of the *Sonifying Visuals + Visualizing Sound* (SV+VS) show at the Fellows of Contemporary Art Gallery, Los Angeles in January 2016, at the Dongdaemun Design Plaza in Seoul, South Korea in August 2016, and at the *CURRENTS NEW MEDIA* Festival in Santa Fe, New Mexico in June 2017. SV+VS was curated by Yoon C. Han and focused on the trans-disciplinary relationships of sound and visuals, "how we listen to visuals and how we see sounds, closing the gap between two different sensory expressions by using the development of technology" (Han, 2016). The show included works by artists such as Reza Ali, YuanYi Fan, George Legrady, Ryan McGee, Juan Manuel Escalante, Erick Oh, and Camilla Kim. Les Colonnes Sonores was also exhibited and published in the Media, Art and Technology's End of the Year show titled *White Noise* at UCSB in June 2016.

The full set of drawings and soundscape is located in the following website: https://www.fmyles.com/works/#/colonnes-sonores/

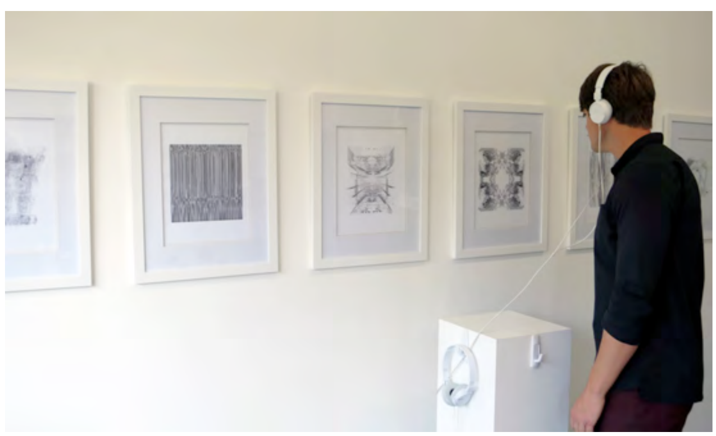

Figure 140: Les Colonnes Sonores at the FOCA Gallery in Los Angeles

5.23 Sound and the Hollyhock House

Sound and the Hollyhock House is a project that examines the archimusical characteristics of Frank Lloyd Wright's Barnsdall House (The Hollyhock House) in Los Angeles. This project transforms data associated with the material proportions of the House into new archimusical compositions using sonic and spatial sampling. This project is a continuation of the previous project, Sound and the Schindler House, and has a kindred legacy. Rudolph Schindler came to be in Los Angeles and thus designed and built the Schindler House because of an opportunity presented by Frank Lloyd Wright to help oversee the construction of the Hollyhock House. Both the Schindler and Hollyhock houses exhibit a beautiful quality of early 20th century modernism; however, the Hollyhock House embodies an exceptional kind of quality due to its many design traits.

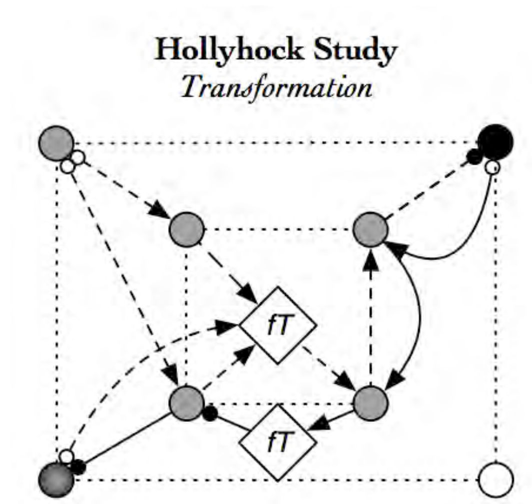

Figure 141: Sound and the Hollyhock House AmTM Constellation

The Hollyhock House built for Aline Barnsdall is an exemplary work whose design is influenced by nature and Wright's theory and practice of *Organic Architecture*. Organic Architecture focuses on designing and building architecture that is harmonious with both the natural environment and humanity. Wright's approach has a similar perspective as the classical concept of *Genius Loci* – meaning the '*spirit of a place*.' This method includes an acute sensitivity to the surrounding environment, history, and culture of a site.

Figure 142: Hollyhock flower and cast concrete artifact by Wright

Archimusic embodies the practice of Genius Loci at a fundamental level, and it comes as no surprise that Frank Lloyd Wright understood the importance of music and its relationship to architecture, having mentioned it in his writings. For example, in his autobiography, he states, "The symphony, as my father first taught me, is an edifice of sound. I now felt Architecture not only might be but ought to be symphonic in character" (Wright, 2005). This quote embodies the very point that strikes the heart of how music and architecture are different modalities of the same principle dealing with the built elements, their structure, and purpose. He also instilled the importance of music by including music rooms in many of his designs, including the Hollyhock House.

Figure 143: Photo of the Hollyhock House Courtyard

The principle design element of the Hollyhock House is the symbolic abstraction of the Hollyhock flower synthesized in the cast-concrete details of the facades, graphic composition of the art glass, and furniture design. Together, these components create a holistic assemblage – each architectural element being an integral part of the whole arrangement. This comprehensive approach exhibited by integrating the generated motif is an architectural and geometric equivalent to the musical concept of theme and variation, reaffirming the impressions of the Hollyhock House's musical nature and the symphonic spaces of Wright's work. Sampling the house focused on these design elements found in the interior spaces of the living, music, dining, and master bedrooms, and introduces the exterior of the house by incorporating the west facade.

Sonic sampling utilizes contact microphones attached to the materials and introduces condenser microphones to record the ambient environment. The arrangement and the number of contact microphones are different from the previous Schindler project, which used one contact microphone to sample the individual materials. In this project, four contact microphones were placed in each room, one on each side, providing an increased resolution recording of the space. Additionally, the ambient sounds of each space were recorded by placing XY condenser microphones in the center of each space, giving a total of six sonic channels for each respective area. The condenser microphones were also used to sample the ambient spaces in the central courtyard and north patio of the house.

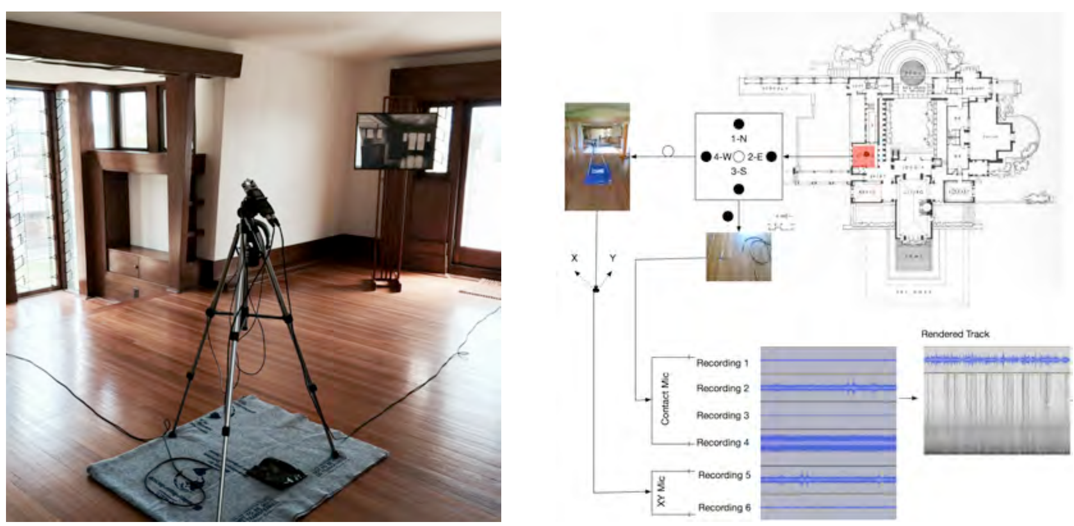

Figure 144: Recording the sonic material and diagram of sonic channels

Spatial sampling utilizes a Kinect camera to 3D scan the spaces similar to the Schindler study. Better resolution scans are collected by mounting the Kinect camera to a tripod placed in the center of each sample space at the same location as the XY condenser microphone and turning it slowly 360° in a circle. In addition to the Kinect camera, *photogrammetry* is used to assemble scans with increased resolution and color. Photogrammetry uses overlapping digital photographic images to map the distances between pixels from different locations to create scans with better resolution. *PhotoScan* processed the points clouds from the photographs of the outside west facades of the house, which exhibit variations of the central Hollyhock element theme as well as the overall proportions of the space.

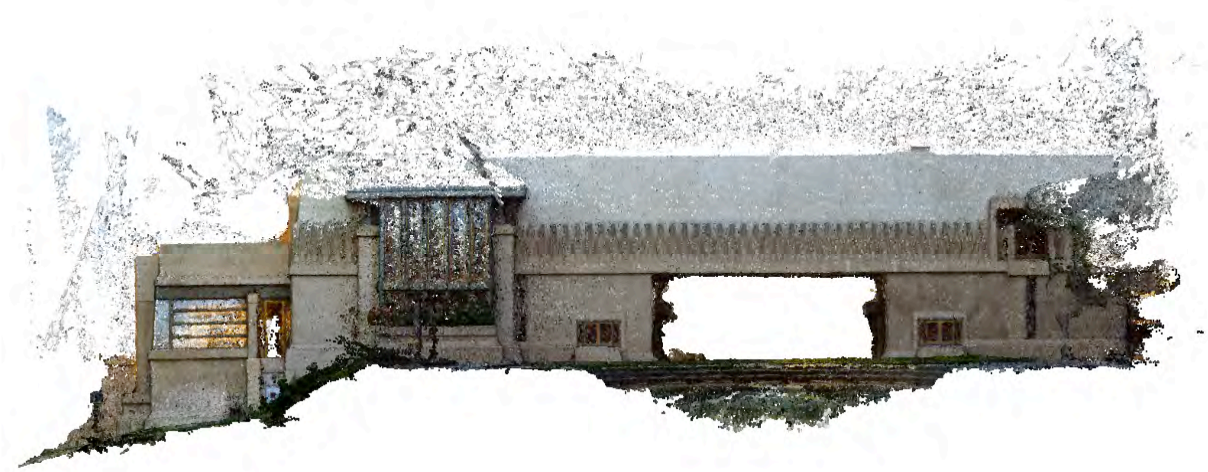

Figure 145: Point cloud of west facade using photogrammetry

The collected 3D scans are brought into the MeshLab for cleaning, while a base model of the 3D plan in Rhino verifies the alignment and scaling. The spatiotemporal material is saved, cataloged, and imported into Kosmos for the generation of archimusical transformations. The point cloud file and the six sound samples from each space are loaded and convolved together using the allogram, resulting in an evolving geometric point cloud and corresponding sonic composition of each space. The sonification process in the Hollyhock project includes additional sound synthesis methods including AM and FM Synthesis, rather than the pure sine tones used in previous studies. These new synthesis techniques develop more complex timbres, which enrich both the sonic and in turn, geometric materials.

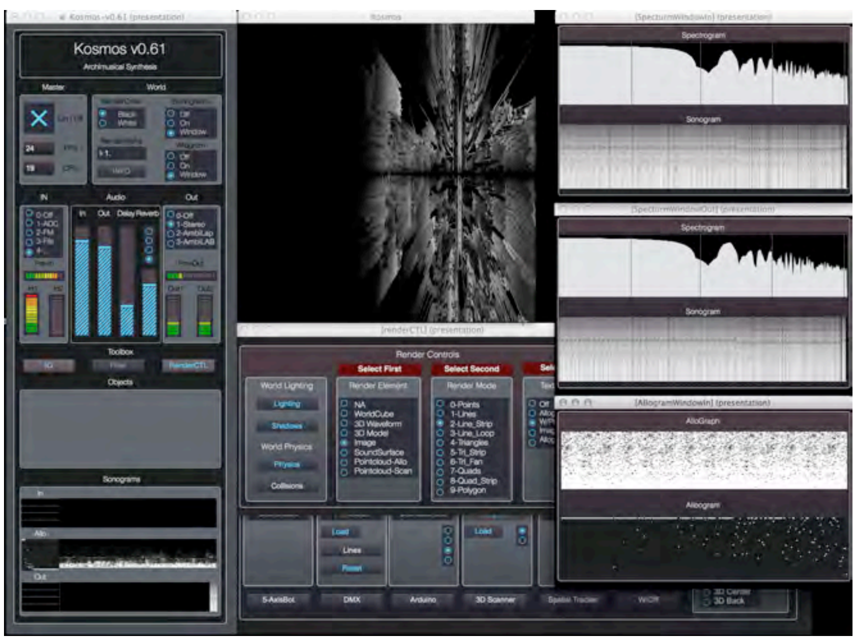

Figure 146: Kosmos screenshot during transformation of Hollyhock artifact

During the process, certain moments are selected and exported as sound files (.wav) and 3D point cloud geometric files (.obj) to produce a series of drawings and soundscapes that illustrate frozen geometric moments, while the layered textures of the soundscape unfold through time. These drawings and accompanying soundscape illustrate different modalities of the same archimusical forms which unify the spatial and sonic materials. Generating new compositional forms from the sampled material promotes the exploration of archimusic and new methods of trans-disciplinary thinking, embedding the unique character of collected material into novel forms. The drawings and soundscape exemplify qualities of this unique place and emphasize the capability for technology to create contemporary integrations within the discipline of architecture.

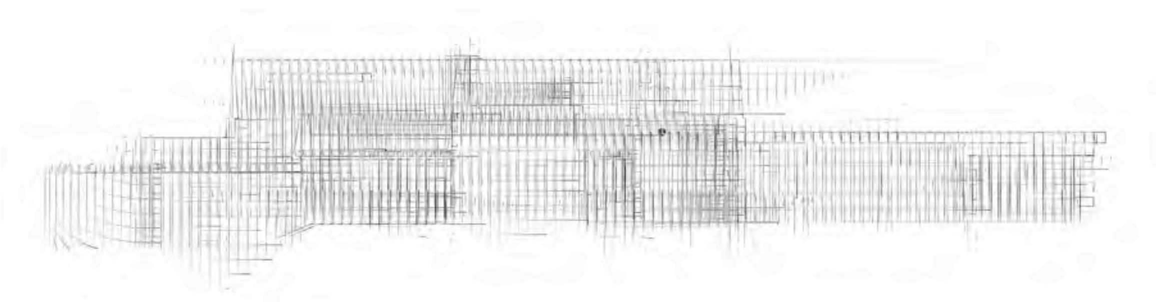

Figure 147: Resulting archimusical elevation drawing of the Hollyhock House

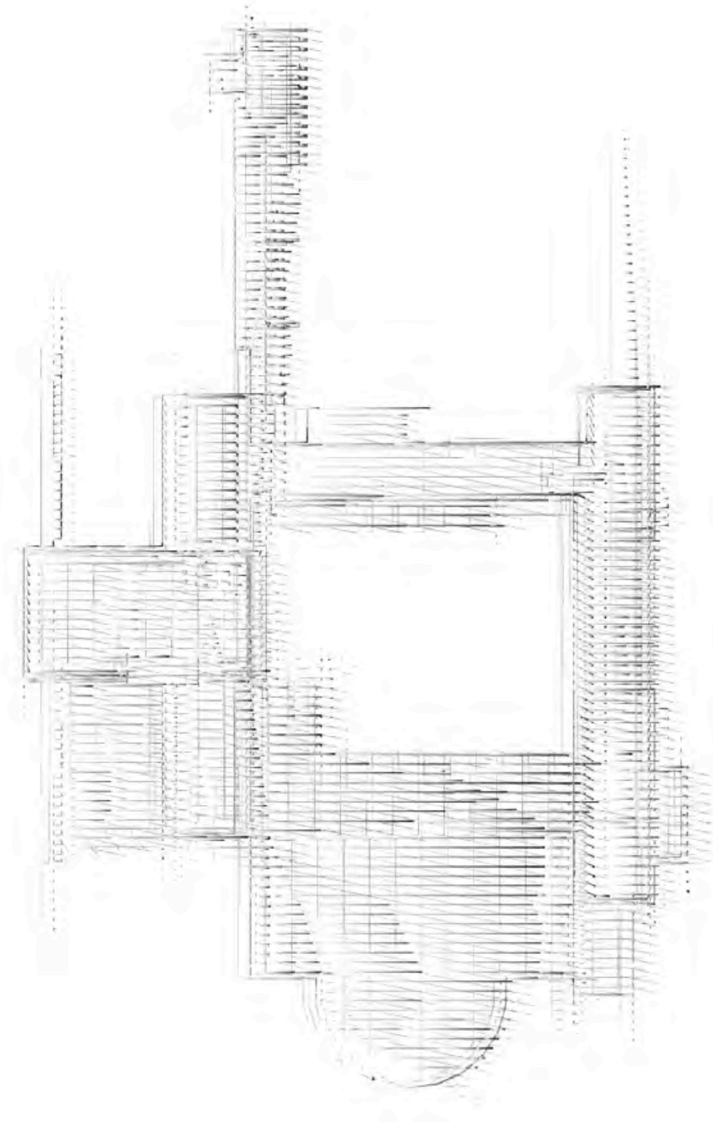

Figure 148: Resulting archimusical plan drawing of the Hollyhock House

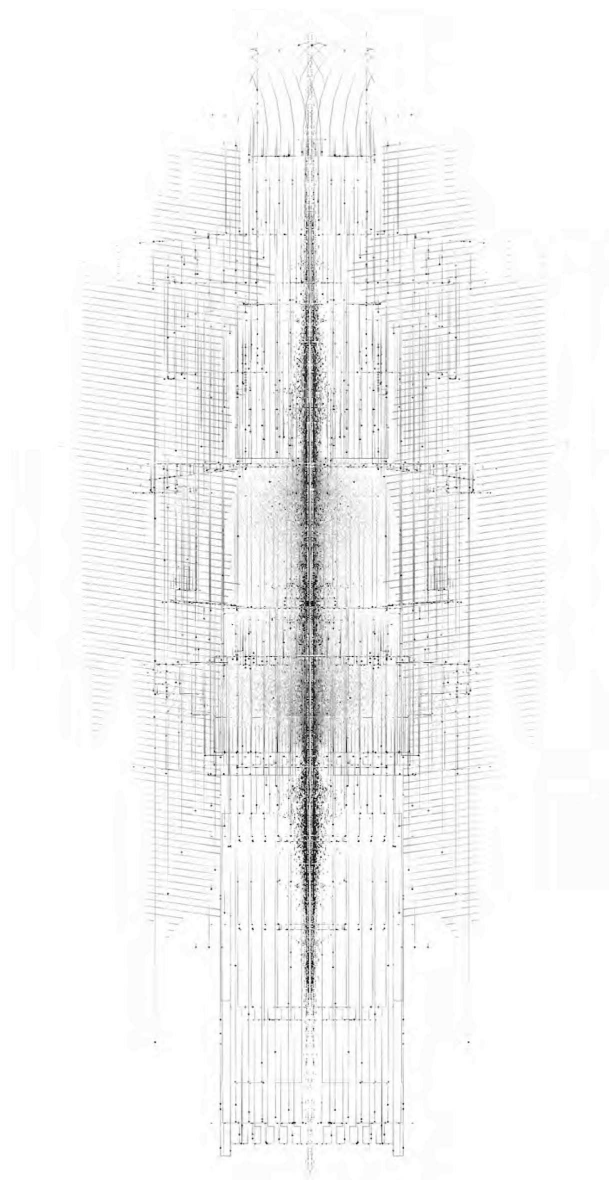

Figure 149: Archimusical drawing of the Hollyhock artifact

The Sound and the Hollyhock House was exhibited at the Media Art and Technology's End of the Year show titled *White Noise* at UCSB in June 2015 and at the Art, Design, and Architecture Museum at UCSB's summer show titled *Computation and Expression* in June 2016.

The full set of drawings and soundscape is located in the following website: https://www.fmyles.com/works/#/hollyhock/

Figure 150: Sound and the Hollyhock House at Computation and Expression show in Santa Barbara

5.24 Sound Scans Conclusion

Sound Scans explore the transformation of existing architectural forms and spaces by utilizing multiple translational techniques introduced in the Initial Studies, including 3D models and audio recordings, along with 3D scanning. These projects continue the translational explorations of the Initial Studies into the topic of transformations. The advancements experimented in these studies resulted in archimusical drawings, virtual 3D models, and soundscape compositions, which explored the unique visual and aural character of architectural spaces and forms.

Sound and the Schindler House explored the archimusical transformations of the Schindler/Chace House by Rudolf Schindler in Los Angeles, California, by re-imagining an existing architectural space using archimusical methods. Spatial and sonic sampling used Kinect 3D camera and contact microphones attached to the materials of the house. Schindler's concepts of an "evolving architecture for the senses," "the raw material of space," and "space as the medium of art" were engaged throughout the process to amplify the inherent characteristics and expressed how the multiple modalities of archimusic offer an enriched perspective of existing architectural space.

Les Colonnes Sonores examined an architectural element rather than an architectural space. This project looked at the sonic concept of harmonics in the spatial and architectural realm by using a classical Greek Corinthian column, which embodies the elegant sensibilities of proportion within geometry. Sonic harmonics and architectural proportion are inherent within the composition of archimusical forms, and experimenting with the integration of these topics illustrate another path forward in the exploration of new archimusical elements.

Sound and the Hollyhock House explored the transformation and generation of new archimusical forms from Frank Lloyd Wright's Hollyhock House in Los Angeles, California. This project increased the resolution and incorporation of additional techniques to explore an existing architectural space with more detail and variation. The improved resolution was achieved by incorporating multi-channel microphone arrays within each room to capture the ambient life of the respective area, while better resolution 3D scans were obtained by combining a circular method using tripods and incorporating photogrammetry to include the exterior facades and the addition of color into the project. These techniques proved successful at providing additional material and better resolution of the space.

Each of these projects illustrate different methods the field of archimusic can explore in the future and puts forth approaches that offer an innovative level of understanding due to the trans-disciplinary relationships.

Additional drawings and the soundscapes of these three projects are located at: https://www.fmyles.com/works/

5.3 Allotope

Inspired by Xenakis's Polytopes, the *Allotope* aims to keep this concept alive and evolving. The Allotope is an archimusical composition that uses the contributions of this research to generate a new archimusical work that embraces a unique site (tope) where the audience is exposed to an expressive and transformative environment. Bringing together what we have learned from the *Initial Studies* and the *Sound Scans*, this final study explores unifying the modalities of archimusic. The goal of this study is to develop a complete and total work of art (Gesamtkunstwerk) by composing with all the modalities simultaneously. The transformative archimusical material of the Allotope is in turn exhibited in multiple modalities.

In this section, we present the *Allotope Krotona* and the importance of the selected site. Next, we describe the different components and their role in contributing a new original work synthesized from a cultural site including drawings, soundscape, immersive installation, VR experience, and the model of a pavilion structure designed for the chosen site.

5.31 The Allotope Krotona

Allotope Krotona is an archimusical work composed with the characteristics of the *Krotona Institute of Theosophy* in Ojai, California. Sonic and spatial sampling and the allogram enable the investigation of new multimodal structures that explore the relationship between sound and space in the making of new archimusical elements. The artifacts of this study result in a series of drawings with an accompanying sound composition along with an immersive audiovisual installation and virtual reality (VR) experience, and a model of a pavilion structure is designed to engage the sonic and architectonic relationships of the selected site. Together the drawings, soundscape, installation, and pavilion are made to exemplify the qualities of this unique place, emphasizing the capability of archimusic to create new integrations and transformations.

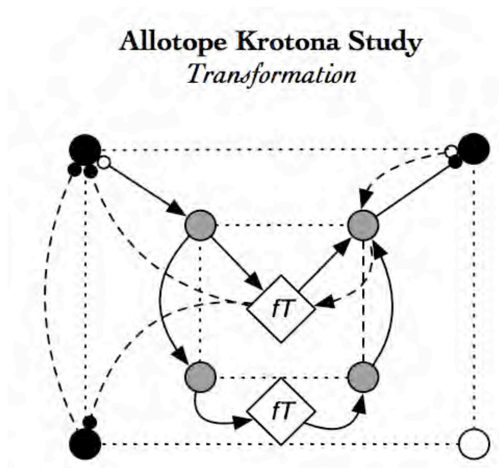

Figure 151: AmTM Constellation of the Allotope Krotona

The Krotona Institute site was chosen for two reasons. First, Krotona takes its name from Crotone, a small town in the south of Italy where Pythagoras, having left Greece, arrived and began his school. As we have discussed, Pythagoras was one of the first thinkers to discover the connection between proportion and harmonics, and is thus essential in the historical lineage of the field now known as archimusic.

Figure 152: Statue of Pythagoras in Crotone, Italy. Image: Dan Beamer

Secondly, since the Schindler House has a connection to Hollyhock House, Krotona has a link to Frank Lloyd Wright through George Gurdjieff who was a student of Wright's wife, Olgivanna Lloyd Wright. Olgivanna had a close relationship with Gurdjieff, a Greek mystic who embodied ancient wisdom through dance and movement, and was an inspiration for the ideals of Krotona and the study of Theosophy. Gurdjieff and Frank Lloyd Wright shared conversations at Taliesin in 1938, and in a letter, Wright writes about Gurdjieff in a manner that illustrates his respect and their shared interests: "*He is a Greek who has roamed about Asia and western Europe in search of the temple rituals of oriental culture. He has from this data by way of the genius that is his, developed new rhythms in the dance and new music so designed as to integrate the human faculties and prepare the man for a more harmonious development than any we can show by way of our current ideas of education.*"

Allotope Krotona also embraces Wright's theory and practice of *Organic Architecture* and the concept of *Genius Loci,* aiming to create a space that is in tune and harmonious with the unique surroundings which a structure is embedded within.

This study begins by selecting three areas of the site including the garden, courtyard, and library. Within the garden, the sonic samples include plants, pathways, trees, and reflecting pool, while spatial samples are obtained using photogrammetry. The courtyard area sonic samples include the fountain, patio, and ambient environment, while photogrammetry is again used to collect the spatial samples. Inside the library, the sonic samples include the floor, walls, and ambient environment, while the spatial samples are collected using both photogrammetry and the Kinect sensor.

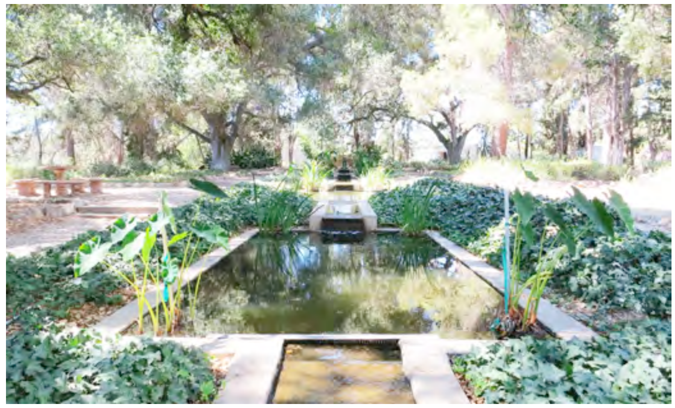

Figure 153: Sampled areas of The Krotona Institute

(garden, courtyard, library)

The sampled material of these three areas is cleaned up and imported into Kosmos for processing. The sampled spatial and sonic material from each corresponding area are arranged into an overall plan of the site, starting from the garden, moving down through the courtyard and arriving at the library. Allograms of each of the spatial and sonic data are made and convolved together, resulting in a final allogram for each sampled space. These areas can now be experienced as an evolving geometric point cloud, and a corresponding sound composition as the samples unfold through time.

Figure 154: Photogrammetry scan of Krotona courtyard

Another sonic translation incorporated into the Krotona study is *Impulse Responses (IR)*. An Impulse response is a method used to record the acoustic properties of a given space using a test tone and convolution reverb, thus making it possible for any source *sound* to be heard as if it were being played in a different spatial setting. This IR study examined the use of IR to generate new spatial forms rather than using the data to filter a source sound. An Impulse Response was taken from the garden using the *HISS toolkit* in MaxMSP (Tremblay, 2017). Data from these IR measurements were used to generate spatial forms in two ways. The first mapped the spectrogram to outlines used in the making of a column-like form, while the second used the frequency and amplitude values to offset a surface, giving rise to a temple-like shape (Figure 153).

As the transformational processes unfold, the material corresponding to the three sampled areas of the site is visualized and sonified, creating the different components of the Allotope. These components include a set of drawings, a generative soundscape, an immersive installation with a VR experience, and a pavilion explicitly designed for the site. The drawings illustrate the different spatial forms as representative structures frozen in time to represent the harmonic proportions taken from the site. The sonic components create the soundscape, composed of both the raw sampled data acquired by the microphones throughout the site and the sonified allogram of the point cloud.

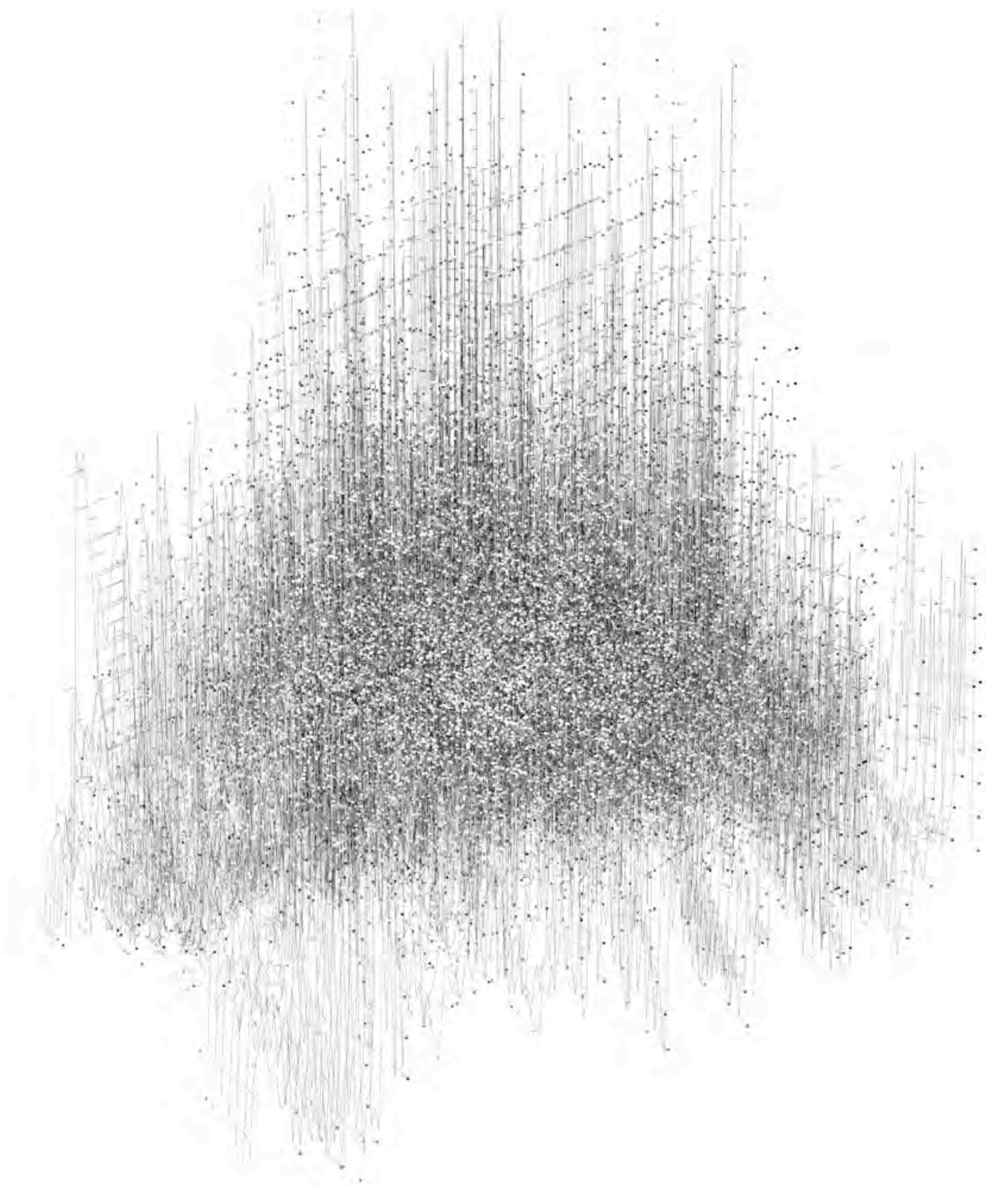

Figure 155: Temple-like form generated from IR data

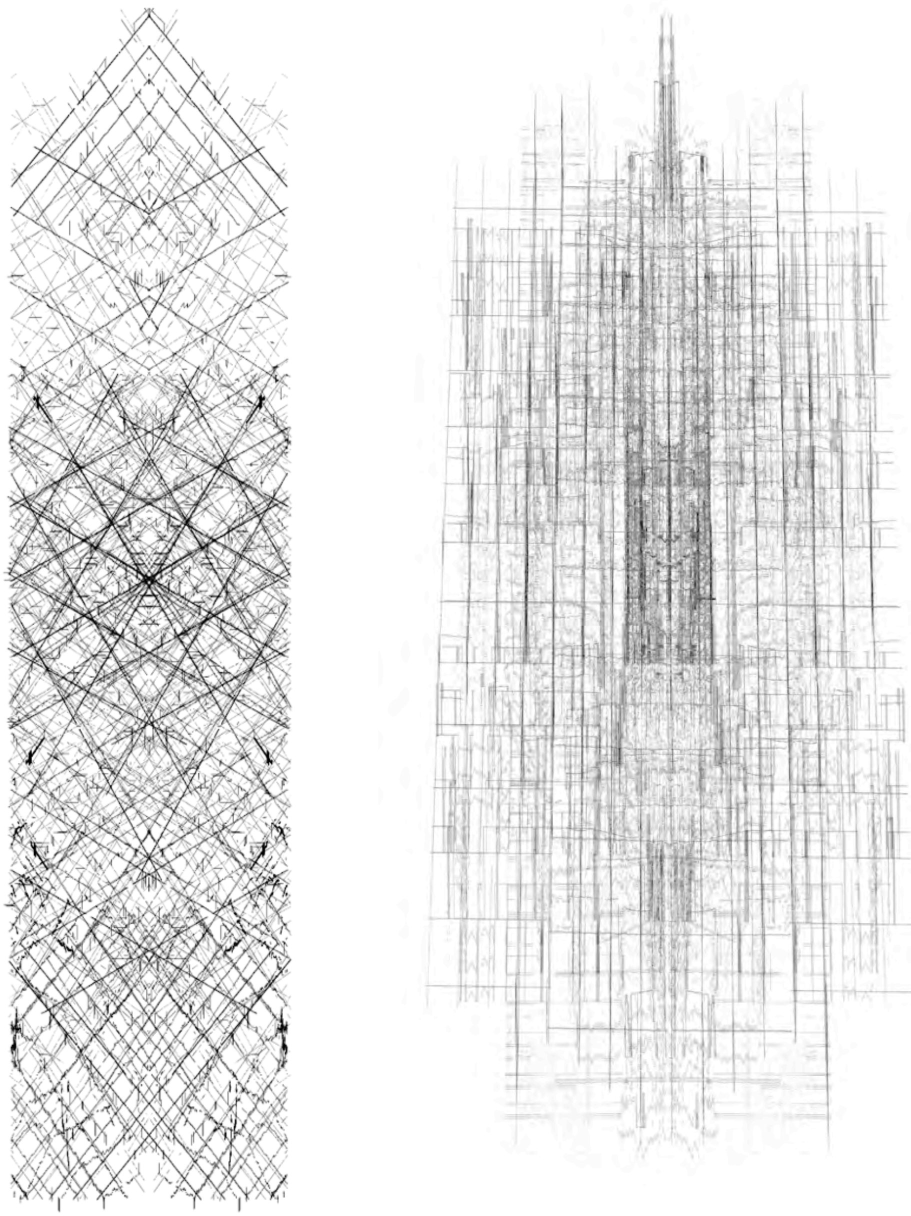

Figure 156: Archimusical drawing generated from sonic and spatial samples of the Library (left) and Garden (right)

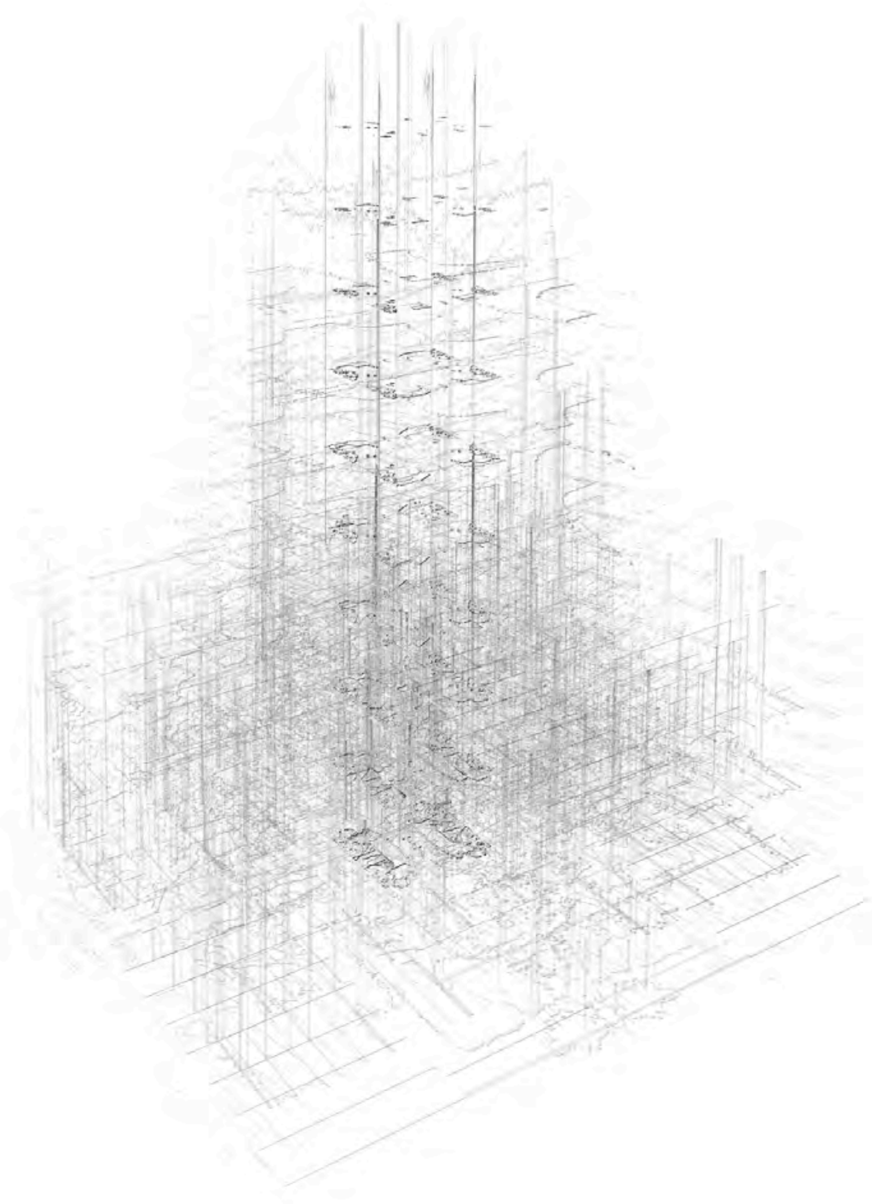

Figure 157: Archimusical axonometric drawing generated from convolved samples of the courtyard

The immersive audio-visual installation emphasizes the three sampled spaces in a 13-minute performance using multiple projections, light sources, spatial sound, and virtual reality (VR). Embracing the qualities of the Polytopes, the Allotope Krotona is a performance where guests are seated on the floor in a semicircle, while a performer wearing a head-mounted display (HMD) navigates a spatial narrative.

The narrative of the Allotope is sequenced through the three areas in a palindrome formation, beginning in the garden, moving through the courtyard and into the library, back through the courtyard, and ending in the garden. Within each rendered space, the point cloud modulates as the soundscape is spatialized through the performance space. Selected modal elements fade in and out as the performer experiences the space in VR. The scene is visible in the VR headset and projected on two walls of the installation.

Figure 158: Allotope Krotona performance with Tim Wood in VR

In the performance of the Allotope Krotona at the *Archimusic Dissertation Defense Exhibition*, dancer, multimedia artist, and Ph.D. student Tim Wood was in the VR headset. As the performance began in the garden, Tim Wood slowly walked through the rendered space, exploring the trees and pathways followed by the shift to the courtyard scene where new data is loaded into Kosmos, and the next chapter unfolds. Once within the surroundings of the courtyard, the modulating point cloud of the sampled area is seen and heard, and the VR performer moves through exploring the fountain and patio areas. After the courtyard sequence has finished, the surroundings fade into the library, and the sample space once again changes, where the user can wander within the modulating space of the library.

Once time in the library concludes, the entire composition reverses itself and once again the user is transported into the courtyard and finally returns to the garden. In the final garden scene, the entire site is visible and able to look beyond to the places traveled and the addition of the Krotona Pavilion, which has emerged standing within the garden that the user can approach. The spatial narrative composed as a palindrome sequence is designed to allow the users to begin experiencing the context of the site entering and exiting the narrative as one experiences a building. Upon returning, the intention is to witness all the site components assembled and embedded into the elements and form of the pavilion structure.

The audience experiences the VR user while seated in an amphitheater configuration. In front of the audience are two visual projections surrounded by a 16.2 channel spatial sound system. Additional layers are evident outside of the VR headset including washes of colors that flow down the walls by four DMX controlled lights composed of the sampled spatial colors from each area of the site and LED point light that flash spontaneously at periodic intervals creating a generative lightning-like effect above the audience, drawing their attention upwards. These LED light strings are designed in stellar constellation patterns, creating a unique metaphor and connecting the heavens to the natural site, fusing the performative modalities into a unique and whole spatial experience.

All of the acquired material is brought together in the composition of the Pavilion model, the last component of the Allotope. The pavilion is composed by rationalizing the resulting point clouds into geometric patterns, embodying the spatial characteristics of the site in a frozen form. The Krotona pavilion is designed to be within the garden, where it can reside in its natural context. and it is the intention to secure funding in the future to build a 1:1 scale pavilion on the site.

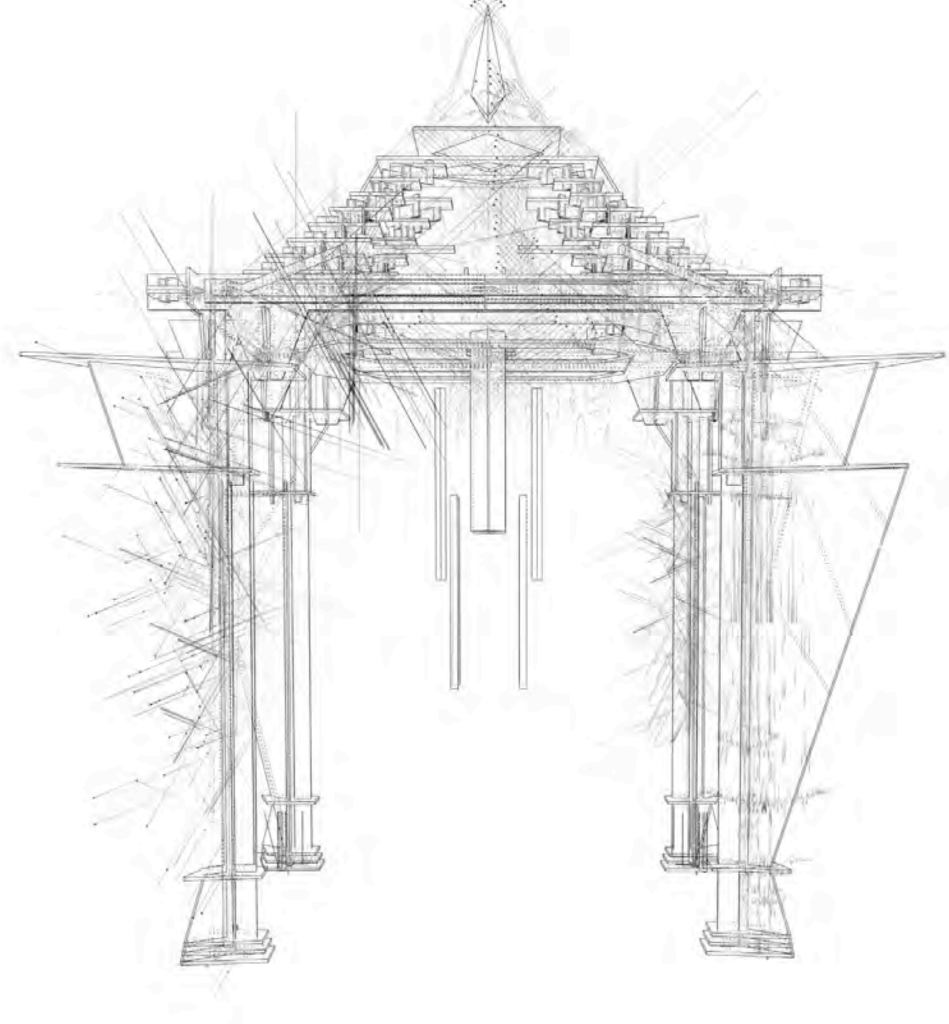

Figure 159: Perspective elevation of the Allotope Krotona Pavilion

Figure 160: Archimusic Exhibition at UCSB

5.32 Conclusion

This study produces an original work that exists in multiple modalities (drawings, soundscape, interactive installation, and pavilion), enabling an innovated experience of trans-disciplinary making. The drawings and soundscape components of the Allotope Krotona were exhibited at the Media Art and Technology's End of the Year Show titled *Re-Habituation,* in May 2017. The installation, including the VR experience and a model of the Krotona Pavilion, was presented at the *Archimusic Defense Exhibition* which introduced the work of this research at UCSB in June 2016. Allotope Krotona is an archimusical study that generates a new and innovative work by integrating the spatial and sonic data of the Krotona Institute.

The full set of drawings and soundscape are located at the following website: https://www.fmyles.com/works/#/krotona/

6. Future Research Directions

"Everything we do is music."
~ John Cage (Kostelanetz, 2003)

This dissertation has provided a thorough foundation for the organization of the field of archimusic, the evaluation of archimusical works and processes, and the generation of new archimusical studies and works. The contributions developed through this research are meant to provide a starting point for the study of the field and informative resources for its continued advancement. Questions naturally arise from the presented research developments and pose both new problems and future research directions. The following paragraphs will present these future research directions within the categories that coincide with the organization of this research and propose possible steps for continued advancement of the field. Future developments will be incorporated in the AOR as the research progresses. It is a hope that this agenda will be pursued by others for further advancement of the field.

6.1 Future directions for the Archimusic Repository

Future research directions of the Archimusical Repository include the continued organization of the field by building upon the resources that have been developed within this research.

All of the projects mentioned in this research are presented in the AOR. Expanding the search to include more projects that fit into this trans-disciplinary field will continue to build the AOR, making it a more complete resource. Thorough research reports on each project and person in the AOR should be conducted as a part of archimusic workshops at conferences or as part of courses taught at institutions. These reports should then be integrated back into the AOR. Additionally, expanding the integrations and methods that have been presented, by developing more in-depth descriptions and examples of each, will contribute to the thoroughness of the presented content. Integrating a subscription list into the AOR, where interested users can stay in contact with new information and events, should also be considered. This list might include an online forum integrated into the AOR for users to engage in discussion and collaborate on research projects.

Additional readers of new subjects and perspectives can be integrated into the current set of readers. These topics could subdivide the presented content into the analysis of particular parts and components of the *Archimusical Transmodal Matrix*. New topics should also be included, such as computational, generative, and artistic approaches, to the field. Lastly, a research publication that annually distributes studies and projects in print and digital form would be a significant contribution. This publication could be included in conferences like ACADIA, eCAADe, and IJAC and could include invited essays and workshops on the topic. A new conference could also be developed including posters and proceedings that promote the study and investigation of the field at the national and international level.

6.2 Future directions for the Archimusical Transmodal Matrix

Future research directions of the *Archimusical Transmodal Matrix* include advancing the evaluation of the field and building upon the methods presented in this research.

The immediate advancement of the Archimusical Transmodal Matrix is to develop an interactive interface for exploring the modalities of the matrix. Building an interface in *JavaScript* or *Node.js* could enable a visual navigation of the matrix that could reference a database from the collection of projects, people, and methods covered in this research. This interactive interface should be embedded into the AOR so that projects and certain modal elements can be isolated and highlighted for use in research studies and in further analysis of certain modal translations and transformations. Additionally, the interface might also be embedded into Kosmos for a fluid workflow from research and evaluation methods and into the generation of new material.

Another future development for the Archimusical Transmodal Matrix might build upon the different domains, which currently focus on the actual and virtual realms of their respective disciplines. Additional domains should include subdivisions of those already explored, divided into smaller sub-components that continue to narrow the focus of the domain. For example, sub-components of the actual domain could include materials, layering, and details, while the virtual domain could be subdivided to focus on the transferring medium, such as computer application, mobile, and web-based applications. Other domains should be introduced that focus on current emerging technologies that are now coming into development such as augmented, virtual, and mixed reality, social networking and gaming.

6.3 Future Directions for Kosmos

Kosmos is a proof-of-concept computational system and additional features are continually being integrated. Future research directions for Kosmos include advancing the computational system for generating new archimusical content and building upon the tools and techniques this research has presented.

Kosmos, as introduced and experimented within this research, is a proof of concept that there are many possible directions for growth and exploration. Building a more efficient interface for the program will enable a more elegant and systematic user experience in using Kosmos with added functionality. One possible approach to this might be to format these functions as a series of modules, which can be included when specific functionality is needed. The following examples are a sample of possible modules that would be particularly interesting to develop.

The concept of theme and variation that was discussed in the Hollyhock House project could be developed into one such compositional module. This module might operate by taking a particular part in a modal element (theme) and develop simultaneous variations side by side, allowing one to visualize multiple variations at once. Similar development for the sonic components, with the use of cross-faders to hear and mix the different aural variations in real time, would be of significant interest to archimusic.

Another possible module would be to further develop the spatial audio component of Kosmos. Spatial audio is included in Kosmos, but has yet to reach its full potential. The next step for this will be to utilize the new ambisonic libraries such as the *HoaLibrary* designed at CICM / University Paris 8 (Sèdes, 2014). Using the spatial audio data could inform entirely new spatiotemporal forms and spaces.

Acoustic sampling data such as reverberation estimation and impulse response (IR) time from existing spaces can be integrated into another possible module. Simple proof-of-concept studies using IR were used in the Allotope Krotona project, but there are many possible directions for future development in this territory as described by Curtis Roads in *Microsound* (Roads, 2004). This module might bridge the gap between archimusic and the acoustic sciences, expanding each field into the other, and helping to find potential overlaps that will lead to novel evaluation, generation, and studies. One such possibility would be to determine the acoustic characteristics and signatures of spatial shapes' examples generated by Kosmos. This could inform the Stockhausenian concept of spaces as developed for particular pieces of music such as his *Musik Haus*. This development could also reverse the technique of producing a piece of music developed specifically for an existing space. It might also introduce the design of new instruments in a similar way by focusing the result toward an object or shape rather than space.

Other developments can be developed in future versions of Kosmos. These include pushing the resolution of re-synthesis and exploring how phase could be incorporated into the process in a significant way. Exploring how certain audio effects from the audio domain appear in the spatial domain and vice versa could prove to be influential of future transformations. Further expanding the use of audio envelopes could provide additional evidence of how the spectrum could be used in novel transmodal processes and explore new questions of spatial mapping and sampling.

Lastly, efficiency is a common factor with most computational systems. Speed and refresh rates are usually a problem in complex computational operations, and when dealing with audio and video simultaneously, this needs special attention, especially in real-time synthesis. While Kosmos runs quite efficiently, it should be ported into a C++

framework for faster operation. *OpenFrameworks* is a great venue due to its large user base, web forum, and ability to incorporate other modules for expanded flexibility and use.

These additions are just a handful of examples of new developments for Kosmos. They are meant to offer potential avenues for exploration and study. The investigation of any one of these would likely provide other possible directions that could inform the trans-disciplinary processes and push new versions of Kosmos forward, as well as potential material for future PhD research topics.

6.4 Future Archimusical Studies

Future research directions for archimusical studies include advancing the investigation into new translations and transformations and building upon the studies this research has presented. In further studies, better resolution 3D scans could be made by using a higher-quality scanner, such as the *Faro X130*. It is in the interest of this research to secure funding to use one of these in future studies.

This research has approached the study of archimusic from a Western perspective. Other cultures also have strong connections between their visual and aural worlds and have a rich and interesting history of both architecture and music. Expanding this research into other parts of the world, including Middle-Eastern and Eastern cultures, would be a fascinating endeavor and would likely provide a great deal more evidence toward the trans-disciplinary connections of architecture and music of different cultures.

A sonic study of facades is a potential step in the Les Colonnes Sonores project, which looks at architectural columns. It would be in the interest of this research to select facades that present a level of detail and ornamentation that showcases the potential of reading the facade as a spectrogram. Another example would be to extend the methods of analysis to generate new facades by taking certain pieces of music and developing facades from their sonic data.

Additional archimusical studies could include expanding the Sound Scan studies into other architectural typologies, including skyscrapers, cathedrals, and the urban scale—taking city street facades and urban plans into account. These studies could examine the city and archimusic, shifting the perspective of buildings as instruments and the city as a symphony.

7. Conclusion

"Architecture is frozen music…

the tone of mind produced by architecture approaches the effect of music."

~ Johann Wolfgang von Goethe (Von Goethe, 1852)

This dissertation has presented an organized body of knowledge on the field of *Archimusic* and the novel methods of *Archimusical Synthesis*. This research has presented three contributions that advance the field of archimusic, including a sound understanding of the past developments between the fields of architecture and music (*The Archimusical Repository*), a novel way to investigate trans-disciplinary works that integrate the fields of architecture and music (*The Archimusical Transmodal Matrix*), and a system for the development of contemporary archimusical works (*Kosmos*). Additionally, a series of studies illustrating new archimusical generations toward new ends has been presented.

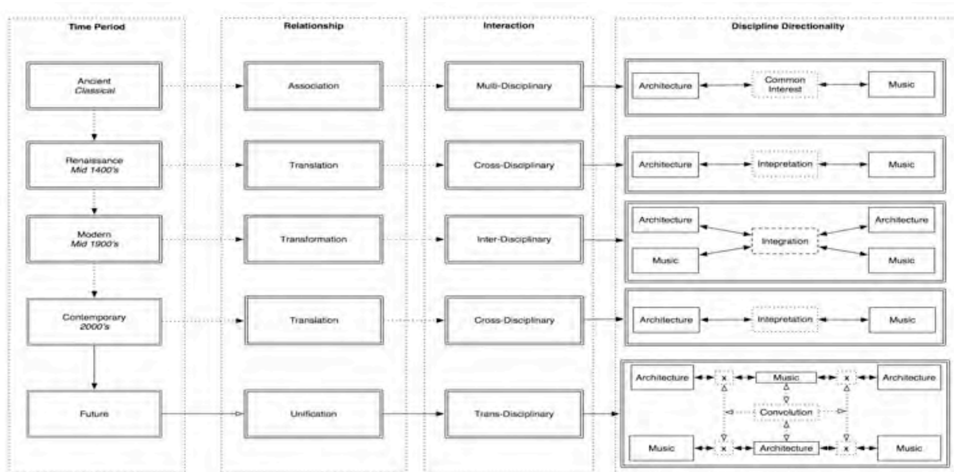

Figure 161: Trans-disciplinary integrations unify the relationships

Below are the findings of this dissertation presented with a discussion of their significance.

1. The Archimusical Repository

Resolving the need of a learning resource for those who are interested in and conducting research on the subject of archimusic, the Archimusical Repository has collected, arranged, and categorized the available resources for the study and advancement of the field of archimusic. This repository provides unique, interdisciplinary integrations between architecture and music, and acts as both a starting point and knowledge resource for researchers interested in the study of the interdisciplinary field of archimusic.

The Archimusical Repository has collected works, studies, and people found in over 150 different sources into one place and serves as a thorough starting point for anyone interested in the relationships between architecture and music. The Archimusical Repository consists of two components, the first is the *Archimusic Online Repository* (*AOR*) which surveys the archimusical people, projects, and information using a website. This includes an interactive timeline that supports the chronological display of the information and a research blog that regularly posts news, events, and information involving the field. The second component described is the *Archimusic Readers*, which have been assembled as a six-volume series covering the field of archimusic, subdividing the discipline into topics such as *Architecture and Music, Notation and Instrumentation, Transformation and Composition, Archimusical Works of Iannis Xenakis*, *Philosophical Considerations*, and *Translation and Transformation Studies*. These readers are designed to provide students and researchers with an informative resource for the continued study and investigation of the archimusical field. The AOR organizes and frames the archimusical field, both serving as a knowledge resource and supporting the dissemination of archimusic for those interested in continuing this research and incorporating it into teaching curricula.

2. The Archimusical Transmodal Matrix

Resolving the need for a contemporary evaluative study with the goal of understanding the transmodal processes and transformational integrations, the Archimusical Transmodal Matrix has been developed as an integrative taxonomic method for evaluating and analyzing the unique compositions that result from the modalities, processes, and integrations that archimusical projects embody.

The *Archimusical Transmodal Matrix* provides the infrastructure and framework for mapping and categorizing the starting point, ending point, and translational processes of an archimusical work's generation. The layout of the disciplines, modalities, and domains of the archimusical field create the structure of the AmTM and the different modal elements that are represented by the matrix. Mapping the relationships between the modal elements using vectors and their associated functional relationships, illustrate the important differences between *apparent* and *concrete* relationships. The *AmTM Constellation* has described how to map archimusical projects in a simple and elegant way, with some example constellations for reference to evaluate the different relationship methods. Lastly, the AmTM has identified the new territory of *Actual Virtual Architecture* [va(A)] to explore using the digital processes of 3D scanning and point clouds. The use of this method has enabled a more thorough understanding of the details and relationships that exist in past and contemporary archimusical projects. This understanding allows for the study of domain specific modalities and the integrative processes that a multimodal archimusical work undergoes, bringing increased resolution to the field of archimusic, and enabling deeper exploration in the future.

3. Kosmos

Resolving the need for digital tools that promote the generation of archimusical forms, using contemporary computational methods, a novel generative system called Kosmos has been developed and promotes the production of novel archimusical forms.

Kosmos enables the transformations of actual and representational modalities of the digital fields of architecture and music. This is accomplished by creating a computational system that allows a fluid workflow, whereby the materials and processes of these modalities are abstracted and treated as a liquid form, able to exist in all modalities at once. This generative compositional system has been developed from the ground up to explore and experiment with the modalities of architecture and music simultaneously. The computational framework, modal elements, layout, and interface of Kosmos have been presented along with illustrated diagrams. The *Archimusical Synthesis* methods—including *spatiotemporal sampling* and *allograms* have demonstrated how Kosmos seeks to unify the field of archimusic. These methods work by creating a digital representation of the musical and architectural domains, integrating their respective digital modalities, using the spectrum as a transformative mediator to compose within the spatial and temporal dimensions of archimusic. Together, Kosmos and the methods of *Archimusical Synthesis* harmonize and influence the unique needs and strengths of both architectural and musical design systems, which have been brought together into one system to advance the generation of archimusical works.

4. Archimusical Studies

To resolve the need for works of archimusic that illustrate new directions for the field, the contributions of this research are used in the exploration of new Archimusical Synthesis Studies. These proof-of-concept studies explore the archimusical territory using the contributions of this research toward different ends and aim toward demonstrating how innovative archimusical works can be achieved.

The goal of these *Archimusical Synthesis Studies* is to exhibit certain aesthetic qualities that arise from the spectral complexity of spatial data. The archimusical studies aim to explore territory that illustrates new directions using the archimusical concepts and contributions of this research. A selection of projects from three categories has been presented. First is the *Initial Studies*, which focus on simple modal translations including using basic geometric shapes, sounds, drawings, and spaces into sonic spectrums and vice versa. Next, the *Sound Scans*, which concentrate on the transformation of existing architectural spaces and elements by utilizing 3D scanning, models, and sonic recordings. Lastly, a new archimusical composition called the *Allotope*, which uses the concepts of explored in this research to generate a new archimusical work. *Archimusical Transmodal Matrix Constellations* have been provided for reference and to illustrate how the AmTM is embedded into the compositional process. These works provide contributions to archimusic and to the spatial and sonic arts. The archimusical synthesis studies demonstrate how the new material is not merely a geometric and sonic primitive, but a unique complex assemblage of spatial and temporal characteristics that constitute a new complete whole by integrating modern technologies.

This dissertation is significant not only in providing new models and methods to advance the field of archimusic, but also in framing the field of archimusic as an end in itself, presenting the trans-disciplinary territory as a studied and understood discipline, framed for continued exploration. The developments of this dissertation have contributed new perspectives and approaches to thinking and making with the modalities of archimusic in novel, contemporary, and computational ways. These developments have provided new territory for the trans-disciplinary methodology, archimusical developments, and transmodal studies to continue organizing, facilitating, and generating new archimusical compositions and discourse.

This research has emphasized the ancient meaning and motivations that these two arts intimately share; advancing the transformational methods of archimusic and addressing how to heighten architecture's capacity to create spaces that are in tune with their unique surroundings. It is the purpose of this research that it may inspire how these two arts may continue keep the conversation of archimusic evolving and to inspire each other and progressing and promote more unity, beauty, and harmony within the visual and aural world.

Bibliography

Allen, S. (1998). *Diagrams Matter.* New York: ANY: Architecture.

Amatriain, X. K.-M. (2009). The allosphere: Immersive multimedia for scientific discovery and artistic exploration. *IEEE MultiMedia, 2(16)*, 64-75.

Aquinas, T. &. (1997). *Basic Writings of St. Thomas Aquinas* (Vol. Vol. 1). Hackett Publishing.

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and management in engineering, 11*(3).

Benedikt, M. (2014). *Center 18: Music in Architecture--Architecture in Music* . Austin: Center for American Architecture and Design.

Bermudez, J. A.-B. (2000). Data representation architecture. visualization design methods, theory and technology applied to anesthesiology. *ACADIA* , (pp. 91-102). Chicago.

Bernhard, L. (n.d.). *SOUNDCUBE*. Retrieved from www.bernhardleitner.at: http://www.bernhardleitner.at/works

Blesser, B. &. (2009). Aural Architecture: The Invisible Experience of Space. *Oase, 78*, 50.

Blesser, B. &. (2009). *Spaces speak, are you listening?: experiencing aural architecture.* Chicago: MIT press.

Bostock, D. (1988). *Plato's Theaetetus.* Oxford.

Bragdon, C. (2005). *The Beautiful Necessity, Seven Essays on Theosophy and Architecture.* Mineola, NY: Cosimo, Inc.

Britannica, E. (2003). *Encyclopaedia Britannica. Millennium 4th Edition.* Chicago .

Cage, J. (1970). *Notations.* Chicago: Something Else Press.

Calter, P. (1998). *Pythagoras & Music of the Spheres.* Retrieved 10 26, 2015, from Dartmouth Mathematics Across the Curriculum project: https://www.dartmouth.edu/~matc/math5.geometry/unit3/unit3.html

Capanna, A. (2009). Music and Architecture: A Cross between Inspiration and Method. *Nexus network journal, 11(2)*, 257-271.

Clements, A. (n.d.). *Moses und Aron review – unmissable, rare Schoenberg opera*. Retrieved 10 26, 2015, from The Guardian:

http://www.theguardian.com/music/2014/may/25/welsh-national-opera-moses-und-aron-review
Corbusier, L. (2004). *The Modulor and Modulor 2* (Vol. 1). Springer Science & Business Media.
Corbusier, L. (2007). *Toward an architecture.* Getty Publications.
Cott, J. a. (1974). *Stockhausen: conversations with the composer.* Pan.
Del Campo, M. (2017). *Evoking Through Design: Contemporary Moods in Architecture.* Chicago: John Wiley & Sons.
Digital-Signal-and-Image-Processing. (n.d.). Retrieved 11 2015, from http://alchetron.com/Digital-Signal-and-Image-Processing-869-W
Doczi, G. (1981). *The power of limits: proportional harmonies in nature, art, and architecture.* Shambhala Publications.
Doxiadis, C. A. (1972). *Architectural space in ancient Greece.* MIT Press.
Ferrera, M. (1996). *The architectural harmony: Mathematics in Greek art and proportions*. Retrieved Juy 12, 2017, from Active Archive Contemporary Art: http://www.caldarelli.it/harmonices/ferrera.htm
Forsyth, M. (1985). *Buildings for music: The architect, the musician, and the listener from the seventeenth century to the present day.* MIT Press.
Garfias, R. (2004). *Music: the cultural context.* National Museum of Ethnology,.
Glissant, E. (1986). Science and Music: An Interview with Iannis Xenakis: Music on the Move. *The UNESCO Courier*, 4-7 .
Goodman, N. (1968). *Languages of art: An approach to a theory of symbols.* Hackett publishing.
Han, Y. C. (2016). *SV+VS (Sonifying Visuals + Visualizing Sound)*. Retrieved from focala: http://focala.org/special-event/svvs-sonifying-visuals-visualizing-sound/
Harley, J. (2004). *Xenakis: his life in music.* Routledge.
Harley, M. A. (1998). Music of sound and light: Xenakis's polytopes. *Leonardo, 31(1)*, 55-65.
Harris, Y. (2002). Architecture and motion: ideas on fluidity in sound, image and space. *Symp. on Systems Research in the Arts*.
Hewett, I. L. (2010). *Iannis Xenakis Composer, Architect, Visionary.* Chicago: The Drawing Center.
Hofmann, B. (2005). Spatial aspects in Xenakis' instrumental works. 193-201.
Holl, S. (. (1996). *Stretto House: Steven Holl Architects.* Chicago: Monacelli Press.

Holl, S. (2008). *DAEYANG GALLERY AND HOUSE*. Retrieved from www.stevenholl.com: http://www.stevenholl.com/projects/daeyang-gallery-and-house

Holl, S. (2012, 9 12). *Stretto House*. Retrieved from www.architectmagazine.com: http://www.architectmagazine.com/project-gallery/stretto-house

Holl, S. (2013). *ARCHITECTONICS OF MUSIC*. Retrieved from 32bny.com: http:///architectonics-of-music-blog

Howard, D. M. (1982). *Harmonic Proportion and Palladio's" Quattro Libri".* The Journal of the Society of Architectural Historians .

Hynes, R. (2009, November 17). *Pavilion 21 MINI Opera Space by Coop Himmelb(l)au*. Retrieved June 12, 2017, from www.dezeen.com: https://www.dezeen.com/2009/11/17/pavilion-21-mini-opera-space-by-coop-himmelblau/

Iddon, M. (2004). The Haus That Karlheinz Built: Composition, Authority, and Control at the 1968 Darmstadt Ferienkurse. *The Musical Quarterly,, 87(1)*, 87-118.

Iliescu, M. (2000). Balint Andras Varga: Conversations with Iannis Xenakis. *Computer Music Journal, 24(1)*, 85-88.

Jabi, W. (2013). Parametric design for architecture. *Laurence King Publ.*

James, J. (1995). *The music of the spheres: Music, science, and the natural order of the universe.* Springer Science & Business Media.

Jencks, C. (2013). Architecture becomes music. *Architectural Review, 233.1395*, 91-108.

Jr., R. W. (2005). *Apple's America Publisher: .* North Point Press.

Kanach, S. (2010). Music to be seen: Tracing Xenakis's Creative Processes. In I. H. Xenakis, *Iannis Xenakis: Composer, Architect, Visionary* (pp. 95-127). Drawing Center.

Kanach, S. a. (2010). *Iannis Xenakis: Composer, Architect, Visionary.* The Drawing Center.

Kipnis, J. (2001). *Perfect acts of architecture.* Chicago: The Museum of Modern Art.

Kircher, A. (1650). *Musurgia Universalis ()* (Vol. vol. 2). Rome. Retrieved from WikiPedia.

Kircher, A. (1966). *Phonurgia nova* (Vol. 44). Broude Brothers.

Kostelanetz, R. (2003). *Conversing with Cage.* Routledge.

Latham, A. (Ed.). (2002). *The Oxford Companion to Music.* Oxford: Oxford University Press.

Lavignac, A. (1903). *Musical education.* New York: D. Appleton.

Levy, A. J. (2003). Real and Virtual Spaces Generated By Music. *International Journal of Architectural Computing, 1(3)*, 375-391.

Libeskind, D. (2002). The Walls are Alive. *The Guardian*.

Lim, L. (2004). *ECSTATIC ARCHITECTURE*. Retrieved from laphil.com: http://www.laphil.com/philpedia/music/ecstatic-architecture-liza-lim

Lobell, J. &. (1979). *Between Silence and Light Spirit in the Architecture of Louis I. Kahn.* Boston: Shambhala.

Lovelace, C. (2010). How Do You Draw a Sound? In I. H. Xenakis, *Iannis Xenakis: Composer, Architect, Visionary* (p. 36). Chicago: Drawing Center.

Lutz, J. (2007). Transpositions: Architecture as Instrument/Instrument as Architecture. . *Essays on the Intersection of Music and Architecture* .

Lutz, J. (2014). Along Parallel Lines: Architectural and Musical Notation. (M. Benedikt, Ed.) *CENTER 18: Music in Architecture—Architecture in Music*, 204-217.

M., N. (1991). Liquid Architectures in Cyberspace. In M. Benedickt, *Cyberspace: first steps.* The MIT Press. Retrieved from http://www.zakros.com/liquidarchitecture/liquidarchitecture.html

Mallgrave, H. F. (1996). *Gottfried Semper: architect of the nineteenth century.* Chicago: Yale University Press.

Marc Treib, R. F. (1996). *Space Calculated in Seconds: The Philips Pavilion, Le Corbusier, Edgard Varese* (Vol. 41). Princeton University Press.

Merriam-Webster. (2004). *Merriam-Webster's collegiate dictionary.* Merriam-Webster.

Naik, P. (2012, March 13). *Unbelievable Macro Shots Taken Inside Instruments*. Retrieved from fstoppers.com: https://fstoppers.com/commercial/pictures-unbelievable-macro-shots-taken-inside-instruments-6129

Neiman, B. (2006). Bebop Spaces. *Proceedings of the 2006 ACSA Annual Meeting*.

Novak, L. (2001, Dec 28). The Alien Within. *Arch'it electronic magazine*.

Novak, M. (1989). AN EXPERIMENT IN COMPUTATIONAL COMPOSITION. *New Ideas and Directions for the 1990's*.

Novak, M. (1991). Liquid Architectures in Cyberspace. In R. &. Packer, *Multimedia: From Wagner to Virtual Reality* (p. 272). W. W. Norton & Company.

Novak, M. (1992). *The Music of Architecture, Computation and Composition.*

Oswalt, P. (2001). Architecture of Densities. *Présences de Iannis Xenakis*, 211-215.

Padovan, R. (2002). *Proportion: science, philosophy, architecture.* Chicago: Taylor & Francis.

Palladio, A. (1965). *The four books of architecture.* Chicago: Courier Corporation.

Pallasmaa, J. (2009). The thinking hand: Existential and embodied wisdom in architecture.

Pallasmaa, J. (2011). The embodied image: imagination and imagery in architecture.

Pallasmaa, J. (2012). *The eyes of the skin: architecture and the senses.* John Wiley & Sons.

Partner, W. D. (n.d.). *Soundscaping*. Retrieved 10 26, 2015, from http://www.coop-himmelblau.at/architecture/projects/pavilion-21-mini-opera-space/

Pasoulas, A. (2008). An Overview of Score and Performance in Electroacoustic Music. *eContact*.

Pentcheva, B. V. (n.d.). *Icons of Sound*. Retrieved 01 26, 2016, from Icons of Sound: http://iconsofsound.stanford.edu

Pollio, V. V. (1914). *The ten books on architecture.* Chicago: Harvard university press.

Press, T. A. (25, June 2008). *Jerusalem's Bridge of Chords*. Retrieved from haaretz.com: http://www.haaretz.com/israel-news/travel/jerusalem-s-bridge-of-chords-a-new-addition-to-city-of-ancient-symbols-1.248468

Prix, W. (2011). *What's the Difference Number One.* . (S. C. Architecture., Producer) Retrieved from SCI-Arc Media Archive: https://sma.sciarc.edu/video/wolf-prix-whats-the-difference-number-one/?hilite=%22prix%22

Prix, W. (n.d.). *Pavilion 21 MINI Opera Space by Coop Himmelb(l)au*. Retrieved 10 26, 2015, from dezeen: http://www.dezeen.com/2009/11/17/pavilion-21-mini-opera-space-by-coop-himmelblau/

Pryer, A. (2014). *Graphic notation.* Latham, Alison (ed.).

Riedweg, C. (2005). *Pythagoras: His life, teaching, and influence.* Chicago: Cornell University Press.

Roads, C. (1996). *The Computer Music Tutorial* . Chicago: MIT press.

Roads, C. (2004). *Microsound.* MIT press.

Roads, C. (2012). FROM GRAINS TO FORMS. In (. Makis Solomos (Ed.), *International Symposium Xenakis. La musique électroacoustique / Xenakis.* The electroacoustic music.

Rowe, C. (1982). *The mathematics of the ideal villa and other essays.* Chicago: MIT press.

Sab, J. a. (2014). Rethinking the Role of Xenakis. (M. Benedikt, Ed.) *Center 18: Music in Architecture--Architecture in Music*, 192.

Sarnitz, A. (. (1988). *RM Schindler, Architect: 1887-1953: A Pupil of Otto Wagner, between International Style and Space Architecture.* Rizzoli.

Schafer, R. M. (1993). *The soundscape: Our sonic environment and the tuning of the world.* Inner Traditions/Bear & Co.

Sciotto, F. (2014). SoundScan: Sound and Spatial Sampling. *ACADIA 14: DESIGN AGENCY* (pp. pp. 147-150). Los Angeles: ACADIA/ Riverside Architectural Press.

Sciotto, F. (2015). *Sound and the Schindler House*. (S. D. Anthony Carfello, Editor) Retrieved from Schindler Lab: http://schindlerlab.org/proposal/f-myles-sciotto/

Sèdes, A. G. (2014). The HOA library, review and prospects. *In International Computer Music Conference*, 855-860.

SEGHERS, M. J. (1964). The golden proportion and beauty. . *Plastic and Reconstructive Surgery , 34.4*, 382-386.

Sikiardi, E. (2007). "Morphologies". *Resonance: essays on the intersection of music and architecture*.

Solomon, L. J. (1973). *Symmetry as a Compositional Determinant*. Retrieved June 2017, from solomonsmusic.net: http://solomonsmusic.net/diss7.htm#Bartok

Stanley, T. (1701). *History of Philosophy Containing the Lives, Opinions, Actions, and Discourses of the Philosophers of Every Sect.*

Sterken, S. (2007). Music as an art of space: interactions between music and architecture in the work of Iannis Xenakis. In *Ressonance: Essays on Intersection of Music and Arquitecture* (pp. 21-51.). Chicago.

Taruskin, R. (2009). *Music in the Late Twentieth Century: The Oxford History of Western Music* (Vol. 6). Chicago: Oxford University Press.

Thiebaut J., H. P. (2008). Drawing Electroacoustic Music. *ICMC*.

Trachtenberg, M. (2001). Architecture and music reunited: a new reading of Dufay's" Nuper rosarum flores" and the Cathedral of Florence. *Renaissance quarterly, 54(3)*, 741-775.

Treib, M. a. (1996). *Space Calculated in Seconds: The Philips Pavilion, Le Corbusier, Edgard Varese.* Princeton University Press.

Tremblay, A. H. (2017). *HISSTools Impulse Response Toolbox*. Retrieved from HISSTools: http://www.thehiss.org/

Von Goethe, J. W. (1852). *Conversations with Goethe in the last years of his life* (Vol. 4). Hilliard, Gray, and Company.

Von Moos, S. (2009). *Le Corbusier: elements of a synthesis.* 010 Publishers.

Warren, C. W. (1973). Brunelleschi's Dome and Dufay's Motet. *The Musical Quarterly, 59(1)*, 92-105.

Webster, M. (2015). Signal Def. 5. Merriam Webster Online.
Wen-Chung, C. (1966). Varèse: A Sketch of the Man and his Music. *Musical Quarterly*, 151-170.
Williams, K. (. (2009). Architecture and Mathematics. *Nexus Network Journal, 11, 2*.
Wittkower, R. (1971). *Architectural Principles in the Age of Humanism.* WW Norton & Company.
Woodstra, C. B. (2005). *All music guide to classical music: the definitive guide to classical music.* Chicago: Hal Leonard Corporation.
Wright, C. (1994). Dufay's Nuper rosarum flores, King Solomon's Temple, and the Veneration of the Virgin. *Journal of the American Musicological Society, 47(3)*, 395-441. .
Wright, F. L. (1992). *Taliesin 1911-1914* (Vol. 1). Chicago: SIU Press .
Wright, F. L. (2005). *Frank Lloyd Wright: An Autobiography.* Pomegranate.
Xenakis, I. (1985). *Arts/Sciences: Alloys.* (S. Kanach, Trans.) Stuyvesant NY.
Xenakis, I. (1992). *Formalized music: thought and mathematics in composition* (Vol. 6). Pendragon Press.
Xenakis, I. (2003). *Musica, architettura.* Spirali.
Xenakis, I. (2008). *Music and architecture: architectural projects, texts, and realizations.* Pendragon Press.
Xenakis, I. a. (1976). *Musique, architecture.* (Vol. Vol. 11). Éditions Parenthèses.
Xenakis, M. (2010). Meteorites. In a. S. Carey Lovelace, *Iannis Xenakis Composer, Architect, Visionary.* New York: The Drawing Center.

Appendix

The following is supplemental and referential material relevant to this research.

A. Glossary

A list of terms found throughout this dissertation and related to this research.

B. Abbreviations

A list of abbreviations used throughout this research.

C. Software Links

A list of software referenced in this research and links to their development sites.

D. Archimusical People, Projects and Methods

A list of those people, projects, and methods of the AOR that have contributed to the relationships between architecture, music, space, and sound.

E. Archimusical Readers

The Table of Contents of each of the AOR Readers.

A. Glossary

- **Archimusic** - Archimusic is the integration of one or more digital or analog modalities from the disciplines of architecture and music toward a new end, such that the components are integrated and non-separable.
- **Associational** – A connection or cooperative link that unite two or more separate entities with one or more common purposes.
- **Allotopes** - An archimusical work that uses archimusical synthesis, including spatiotemporal sampling and allograms in the generation of a novel space-time work.
- **Archimusical Synthesis** - The integration of architecture and music, archimusical synthesis is a form of spatiotemporal synthesis where the spatiotemporal form is generated or changed by integrating the spatial geometric data and the audio data into the same domain using the spectrum as a transformative mediator.
- **Architecture** - The discipline of architecture is commonly defined as the building of structures made for inhabitation. In this research, we use the term *architecture* to mean the physical or virtual composition of structural elements into ordered relationships in or through the dimension of space.
- **Associational** – The connection or cooperative link that unites two separate entities with a common purpose
- **Composition** - Composition is "to put together." In this research, title composition is the ordering of components into meaningful relationships that rely on unity.
- **Conventional** - Based on or are in accordance with what is generally accepted by a culture or subculture.
- **Convolve** - The operation of joining two functions together.

- **Dinergic** - A word coined by Doczi from the Greek dia~ and energy relating to a universal organic pattern-creating process
- **Discipline** - A discipline is a branch of knowledge. In this research, the disciplines in question are architecture and music, as progenitors, and archimusic, emerging from their fusion.
- **Domain** - A domain is a territory that exists within a given modality. In this research, the domains are the physical and the virtual.
- **General Morphology** - The general morphology is the idea of a total work of art between the disciplines of space, light, sound, architecture, and music; cosmic in scale, and focuses on the human senses and philosophical concepts, creating new ways to relate ourselves to a higher-order and the environment.
- **Genius Loci** - A Latin phrase meaning the 'spirit of a place' and used in early architectural and landscape design practices and believed in the methods of designing with nature, culture, and environment including Archetypes and A Priori knowledge.
- **Gesamtkunstwerk** - Wagner's concept of a total work of art that makes use of many art forms.
- **Grain** - A discrete particle or sample that is the smallest component of a sound, typically < 100 ms.
- **Genera** - Genera is the term for the processes of creating elements amongst the subdivisions. Elements are the figure that takes place in the void, ground or datum that is outlined by the taxis.
- **Harmonics** - A component or overtone frequency of a fundamental tone at a fixed interval.
- **Integrations** - The act or process of combining one modality with another so that they become a new whole.

- **Instrumentation** - The design, provision, or use of particular instruments; employed in a manner in which a piece is arranged.
- **Integration** - The process of combining two or more modalities so that they become a new whole.
- **Kinect** - The Kinect is a low-cost camera from Microsoft capable of capturing 3D information including position and color using a structured light algorithm.
- **Multimodal** – The many different types of an object or idea though similar or isomorphic.
- **Modality** - A modality is a particular mode or form in which something exists, is experienced, or is expressed. In this research, the modalities are the actual and the representational.
- **Modal Element -** A modal element represents a particular domain of a particular modality of a particular discipline.
- **Music** - The discipline of music is commonly defined as the organization of sounds into relationships that have emotional effect. In this research, this definition is expanded to include the physical or virtual composition of harmonic structures in or through the dimension of time.
- **Notation** - A series or system of written symbols used to represent numbers, amounts, or elements in something such as music or mathematics.
- **Photogrammetry** - A method which uses overlapping digital photographic images to measure distances between pixels from different locations to create of a 3D scan of the object or space.
- **Point cloud** - A point cloud is a set of data points in a coordinate system that represents a form or space.
- **Proportion** - Proportion is the relationship of one thing to another regarding quantity, size, or number or ratio.

- **Poiesis** - Greek for the "making," with a poetic nature embodied such that it contains an embedded elegance and harmonic component that has an inherent and link to human or cosmic nature.
- **Ratio** - The quantitative relation between two amounts showing the number of times one value contains or is contained within the other.
- **Symmetry** - Symmetry is the process of finding and making relationships amongst the elements within their given taxis. Once the symmetries are made the process
- **Signal** - A signal is a gesture, action, or sound that is used to convey information or instructions, typically by prearrangement between the parties concerned. A signal is an electrical quantity or effect, as current, voltage, or electromagnetic waves that can be varied in such a way as to convey information (Webster).
- **Sampling** - Sampling is the act of taking a portion, or sample, of one sound recording and reusing it as an instrument or a sound recording in a different song or piece.
- **Spectrogram** - A spectrogram is a visual representation of the spectrum of frequencies of a sound or other signal as they vary with time or some other variable.
- **Synthesis** - The combination or composition of particular ideas or elements into a form or system.
- **Timbre** - The character or quality of a musical sound or voice as distinct from its pitch and intensity.
- **Translational** - a formal or technical processes or conversions that enable the movement of something from one form or place to another. A translational interpretation is the conversion of one form or medium into another, or the communication of the meaning of a source-form or field, using an equivalent target language, into a destination-form or field.

- **Transformation** - a relationship of change or alteration of form, shape, procedure or formational process. Transformations are a thorough or dramatic change in one element or form into another that is equivalent in some important aspect but is expressed or represented in a different modality.
- **3D Scanning** - 3D scanning analyses a real-world object or environment to collect data on its shape and possibly its appearance**.**

B. Abbreviations

ACADIA - The Association for Computer Aided Design in Architecture

AmTM - Archimusical Transmodal Matrix

AOR - Archimusical Online Repository

As-builts - A revised set of drawings measured after the completion of a project.

CICM - Centre de Recherche Informatique et Création Musicale

CPU - Computer Processing Unit

DAW - Digital audio workstation is an application for sound and music production.

DFT - Discrete Fourier Transform

DSP - Digital Signal Processing

FFT - Fast Fourier Transform

GPU - Graphics Processing Unit

IRCAM - Institut de Recherche et Coordination Acoustique/Musique

IX - Iannis Xenakis

.**JIT** - Jitter matrix file format

.**JPG** - Joint Photographic Experts Group file format

MAT - Media Arts and Technology Program at UCSB

MIT - Massachusetts Institute of Technology

.**MP3** - MPEG-1 Audio Layer-3 file format

.**OBJ** - Wavefront Object file format

OSC - Open Sound Control

Paris 8 - University of Paris 8

.**PNG** - Portable Network Graphics file format

RGB - Red, Green, Blue

SCI-Arc - Southern California Institute of Architecture

.**TXT** - Text file format

UPIC - Unite Polygogique Informaique de CEMAMu

.**VST** - Virtual Studio Technology is a software interface for audio plugins.

.**WAV** - Waveform Audio file format

.**XYZ** - Point cloud file format

.**XML** - Extensible Markup Language (XML) file format

C. Software Links

- **3D Coa**t - http://3dcoat.com
- **Audiosculpt** - http://anasynth.ircam.fr/home/english/software/audiosculpt
- **Ceetah3d** - http://www.cheetah3d.com
- **Cosm** - http://allosphere.ucsb.edu/cosm
- **Fabric Engine** - http://fabricengine.com
- **Faro** - http://www.faro.com/home
- **Grasshopper** - http://www.grasshopper3d.com
- **HoaLibrary** - http://www.mshparisnord.fr/hoalibrary/
- **Houdini** - *https://www.sidefx.com*
- **HyperScore** - http://hyperscore.wordpress.com
- **IanniX** - http://www.iannix.org/en/
- **Isadora** - http://troikatronix.com
- **JavaScript** - http://javascript.com
- **Mathematica** - http://wolfram.com/mathematica
- **Max/MSP/Jitter** - https://cycling74.com
- **MeshLab** - http://meshlab.sourceforge.net
- **Metasynth** - http://www.uisoftware.com/MetaSynth
- **Node.js** - http://nodejs.org
- **OpenFrameworks** - http://www.openframeworks.cc
- **PhotoScan** - http://.agisoft.com
- **Pure Data** - https://puredata.info
- **Rhino** - http://rhino3d.com
- **Touch Designer** - http://www.derivative.ca
- **VVVV** - http://vvvv.org
- **UPIC** - http://www.musicainformatica.org/topics/upic.php

D. Archimusical People and Projects

Archimusical People

People and projects that have explored the intersection between architecture and music.

Architects

- Marcus Vitruvius Pollio
- Leon Battista Alberti
- Andrea Palladio
- Le Corbusier
- I.M Pei
- Colin Rowe
- Iannis Xenakis
- Frank Gehry
- Lionel March
- Steven Holl
- Daniel Libeskind
- Zaha Hadid
- Tonkin Liu
- Wolf Prix
- Gottfried Semper
- Louis Sullivan
- McKim, Mead & White
- Ralph Adams Cram
- Richard Rogers

Composers

- Richard Wagner
- Arnold Schoenberg
- John Cage
- Pierre Schaeffer
- Iannis Xenakis
- Karlheinz Stockhausen
- Brian Eno
- Curtis Roads
- David Byrne
- Amon Tobin
- Autechre
- Bennett Robert Neiman
- Charles Ives
- Pierre Boulez
- Edgard Varèse
- Steve Reich
- David Byrne

Artists

- Blake Carrington
- Marcos Novak
- Luke Jerram
- Asif Khan
- Pernilla Ohrstedt
- Jan Jacob Hofmann
- Heike Bottcher
- Eila Hiltunen

Architecture

- Chandigarh Secretariat (1953) - Le Corbusier, Iannis Xenakis
- La Tourette (1956) - Le Corbusier, Iannis Xenakis
- Phillips Pavilion (1958) - Le Corbusier, Iannis Xenakis
- Hermann Scherchen Music Studio (1961) - Iannis Xenakis
- Cosmic City (1963) - Iannis Xenakis
- Diatope (1978) - Iannis Xenakis
- Micromegas (1979) - Daniel Libeskind
- Villa Mache Amorgos (1965-1981) - Iannis Xenakis
- Cite de la Musique, Paris (1984) - Iannis Xenakis
- Stretto House (1989) - Steven Holl
- Rock and Roll Hall of Fame (1993) - I.M. Pei
- Reynolds House (1990's) - Iannis Xenakis
- Home Away from Home Corsica (1980's - 1996) - Iannis Xenakis
- EMP (2000) - Frank Gehry
- Piano House (2007) - Hefei University of Technology
- Aura (2008) - Zaha Hadid
- Bach Performance Hall (2009) - Zaha Hadid
- Pavilion 21 MINI Opera Space (2008) - Coop-Himmelblau
- Feedback Space (2008) - Coop-Himmelblau
- BMW Roof (2007 - 2011) - Coop-Himmelblau

Installation & Immersive Art

- Polytope de Montreal (1967) – Iannis Xenakis
- Polytope Persepolis (1971) (Diamorphoses) - Iannis Xenakis
- Polytope de Cluny (1972-74) - Iannis Xenakis
- Polytope de Mycenes (1978) (Mycenae Alpha/UPIC) - Iannis Xenakis

- Diatope (1978) (Legend of Er/UPIC) - Iannis Xenakis
- Sibelius Monument (1961) - Eila Hiltunen
- Caves of Jeita Lebanon (1969) - Karlheinz Stockhausen
- West German Pavilion Osaka (1970) - Karlheinz Stockhausen
- Court of Water Wall (1999) - Heike Bottcher
- Sonic Architecture (2001) - Jan Jacob Hofmann
- Blackpool High Tide Organ (2002) - L. Curtin & J. Gooding
- Playing the Building (2005) - David Byrne
- Panopticon: Singing Ringing Tree (2006) - Tonkin Liu
- CargoGuitar (2011) - M. Ertorteguy, T. Fukuda, S. Valente
- Cathedral Scan (2011) - Blake Carrington
- Aeolus (2011) - Luke Jerram
- Beatbox Pavilion (2012) - Asif Khan & Pernilla Ohrstedt
- Bach Sculpture - Neugeboren

Architecture & Acoustics

- Theatre of Delphi (350 BC) - Trophonios & Agamedes
- Epidaurus (340 BC) - Polykleitos the Younger
- Staatsoper (1838) - Gottfried Semper
- Saint Thomas Church (NYC) (1824) - Ralph Adams Cram
- Auditorium Building (1889) - Louis Sullivan
- Symphony Hall, Boston (1900) - McKim, Mead & White
- Hollywood Bowl (1922, 2004) - Allied, Frank Lloyd Wright, Hodgetts & Fung
- Disney Concert Hall (2002) – Frank Gehry

Architecture & Electronic Sound

- Radio City Music Hall (1932) - Edward Durell Stone

- Phillips Pavilion (1958) - Le Corbusier, Iannis Xenakis
- Jeita Caves Stimmung (1969) - Karlheinz Stockhausen
- West German Pavilion (1970) - Karlheinz Stockhausen
- Spiral Tunnel (1973) - Karlheinz Stockhausen
- Polytope de Cluny (1972-74) - Iannis Xenakis
- Diatope (1978) (La Legend D'Eer, Centre) - Iannis Xenakis
- IRCAM (1978) - Boulez, Rogers, Piano
- TU Berlin WFS Array - TU Berlin (2000)
- Allosphere (2007) - JoAnn Kuchera-Morin, Marcos Novak, Curtis Roads
- Espace media (2010) - Espace
- Music House - Karlheinz Stockhausen

Architectural Scoring

- La Tourette (1956) - Le Corbusier, Iannis Xenakis
- Phillips Pavilion (1958) - Le Corbusier, Iannis Xenakis
- Hermann Scherchen Music Studio (1961) - Iannis Xenakis
- Polytope de Montreal (1967) - Iannis Xenakis
- Polytope Persepolis (1971) - Iannis Xenakis
- Polytope de Cluny (1972) - Iannis Xenakis
- Polytope de Mycenae (1978) - Iannis Xenakis
- La Légende d'Eer (Diatope) – Iannis Xenakis
- Chamber Works (1983) - Daniel Libeskind
- Jewish Museum Berlin (2001) - Daniel Libeskind
- Bebop Spaces (2005) - Bennett Robert Neiman
- Pavilion 21 Opera Space (2008) - Coop-Himmelblau

Spatial Music

- Universe Symphony (1928) - Charles Ives
- Metastasis (1954) - Iannis Xenakis
- Poème Electronique (1957) - Edgard Varèse
- Pendulum Music (1966) - Steve Reich
- Musik fur ein Haus (1968) - Karlheinz Stockhausen
- Stimmung (1969) - Karlheinz Stockhausen
- HPSCHD (1969) - John Cage
- Musicircus (1967) - John Cage
- La Legende D'Eer (1978) - Iannis Xenakis

Graphic Notation

- Le Sacrifice (1953) - Iannis Xenakis
- Studie 1-2 (1954) - Karlheinz Stockhausen
- Metastasis (1954) - Iannis Xenakis
- Gruppen (1955) - Karlheinz Stockhausen
- Pithoprakta (1956) - Iannis Xenakis
- Poème électronique (1958) - Edgard Varèse
- Concret PH (1958) - Iannis Xenakis
- Fontana Mix (1958) - John Cage
- Artikulation (1958) - Rainer Wehinger / Ligeti
- Etudia na jedno uderzenie talerz (1959) - Włodzimierz Kotoński
- Kontakte (1958-1960) - Karlheinz Stockhausen
- Fields of Indeterminacy (1960) - Toshi Ichiyanagi
- Symfonia Muzyka Elektroniczna (1964) - Bogusław Schaeffer
- Terretektorh (1965) - Iannis Xenakis
- Mikrophonie (1966) - Karlheinz Stockhausen

- Nomas Gamma (1967) - Iannis Xenakis
- Musicircus (1967) - John Cage
- Musik Für Ein Haus (1968) - Karlheinz Stockhausen
- Persephassa (1969) - Iannis Xenakis
- Multiple 1 (1969) - Roman Haubenstock-Ramati
- Uberklavier (1970) - Martin Davorin-Jagodić
- Persepolis (1971) (Iran) - Iannis Xenakis
- Muzyka na Taśmę Magnetofonową (1973) - Andrzej Dobrowolski
- Mycennes Alpha (1978) (UPIC) – Iannis Xenakis
- Faeries Aire (1980) - John Stump
- Radical Music (2005) - Llorenc Barber
- Solitude (2013) - Hans-Christoph Steiner
- La Tourette (1956) - Le Corbusier, Iannis Xenakis
- Fontana Mix (1958) - John Cage
- Kontakte (1958-1960) - Karlheinz Stockhausen
- Artikulation (1958) - Rainer Wehinger / Ligeti
- Etudia na jedno uderzenie talerz (1959) - Włodzimierz Kotoński
- Fields of Indeterminacy (1960) - Toshi Ichiyanagi
- Hermann Scherchen Music Studio (1961) – Iannis Xenakis
- Symfonia Muzyka Elektroniczna (1964) - Bogusław Schaeffer
- Polytope de Cluny (1972) - Iannis Xenakis
- Muzyka na Taśmę Magnetofonową (1973) - Andrzej Dobrowolski
- La Légende D'Eer (Diatope) - (1978) - Iannis Xenakis
- Faeries Aire (1980) - John Stump
- Chamber Works (1983) - Daniel Libeskind
- Bebop Spaces (2005) - Bennett Robert Neiman
- Pavilion 21 Opera Space (2008) - Coop-Himmelblau

E. Archimusical Readers

The Archimusic Readers are a multiple volume collection of writings concerned with the intersection of architecture and music.

Copies of the Readers are located at the following places:

- *Downloadable versions:*
  - http://archimusic.info/archimusic-readers/
- *Physical versions:*
  - *Media Arts and Technology (MAT) Department at UCSB*
  - *Southern California Institute of Architecture (SCI-Arc) Library*
  - *University of Southern California (USC) School of Architecture Library*

Volumes:

I. Architecture & Music
II. Notation & Instrumentation
III. Transformation & Composition
IV. Archimusical Works of Iannis Xenakis
V. Philosophical Considerations
VI. Translational Studies

Volume I

Readings on Architecture & Music

- The Music of Architecture: Computation and Composition
  Marcos Novak - 1992
- Resonance: Music and Architecture
  M. Muecke & M. Zach - 2007
- Architecture Becomes Music
  Charles Jencks - 2013
- Introduction and Preface (Music and Architecture)
  Iannis Xenakis - 2008
- Music and Architecture: Confronting the Boundaries
  Jonathon Cole - 2007
- Towards the Future: A New Context for Music
  Micheal Forsyth - 1985
- Architecture & Music
  Ulrich Winko
- Architecture Writings (Music and Architecture)
  Iannis Xenakis - 2008
- Site + Sound: Space
  Kourosh Mavash - 2007
- Concerning Time, Space and Music
  Iannis Xenakis - 2001
- Preliminary Statement by Iannis Xenakis (Alloys)
  Iannis Xenakis - 2010

Volume II

Readings on Notation & Instrumentation

- Along Parallel Lines: Architectural and Musical Notation
  Jim Lutz - 2014
- Music and Architecture: A Cross between Inspiration and Method
  Alessandra Capanna - 2009
- Drawing Electroacoustic Music
  Thiebaut, Healey, Kinns - 2007
- Music to Be Seen: Tracing Xenakis' Creative Process
  Sharon Kanach - 2010
- Notation
  R. Murray Schafer - 1994
- Musical Space and Architectural Time
  Hanoch-Roe, Galia - 2003
- Scoring the Path
  Hanoch-Roe, Galia - 2007
- Transpositions: Architecture as Instrument/Instrument as Architecture
  Jim Lutz - 2007
- How Do You Draw a Sound?
  Carey Lovelace - 2010
- The UPIC System
  - Sharon Kanach - 2008
- Architecture and Motion: Ideas on Fluidity in Sound, Image and Space
  Yolande Harris – 2002

Volume III

Readings on Transformation & Composition

- The Poetics of Order (Logos Opticos)
  Tzonis - 1986
- Computational Composition in Architecture
  Marcos Novak - 1992
- Ornament in Architecture
  Louis H. Sullivan - 1892
- Architectural Composition (What is Architecture)
  John Beverley Robinson - 1908
- Markov Chains (Book of Screens) | Sieves
  Iannis Xenakis - 2001
- The Mathematics of the Ideal Villa
  Colin Rowe - 1982
- The Logic of Architecture (Languages of Architectural From)
  William Mitchell - 1990
- Geometry in Time
  Greg Lynn - 1998
- The Geometry of Musical Chords
  Dimitri Tymoczko - 2002
- Grains to Forms
  Curtis Roads - 2012
- Sound Transformation
  Curtis Roads - 2015

Volume IV

Readings on Archimusical Works of Iannis Xenakis

Volume V

Readings on Philosophical Considerations

- The Republic (Chapter 7 & 10)
  Plato
- Architecture, Essay on Art
  Etienne-Louis Boullee - 1953 (1778-1788)
- The Age of the World View
  Martin Heidegger - 1976
- The Question Concerning Technology
  Martin Heidegger - 1977
- The Origin of the Work of Art
  Martin Heidegger - 1977
- The Actual and the Virtual
  Gilles Deleuze & Claire Parnet
- Smooth and the Striated
  Gilles Deleuze - 1980
- Simulacra and Simulation
  Jean Baudrillard - 1995
- The Medium is the Message
  Marshal McCullhan - 1964
- Form and Art in Architecture (Intro)
  Eliel Saarinen - 1948
- The Changing Concept of Proportion
  Rudolf Wittkower - 1960

Volume VI.i

Readings on Translational Studies

- Experiments in Computational Composition
  Marcos Novak – (2007)
- Appropriating an Architectural Design Tool for Musical Ends
  Michael Fowler (2012)
- Designing Sounds and Spaces: Interdisciplinary Rules & Proportions in Generative Stochastic Music and Architecture
  Kirsty Beilharz (2004)
- The Shape of Sound: Using Mixed Realities to Bridge Music and Architecture
  Wang & Chen (2008)
- Rethinking Xenakis and the Role of Information
  A. Lucia & J. Sab - (2014)
- Mutual Relation Role Between Music and Architecture in Design
  Dewidar, El-Gohary, Aly, Salama - (2006)
- The Control of Shape: Origins of Parametric Design in Architecture in Xenakis, Gehry and Grimshaw
  ALVARADO, MUÑOZ - (2012)
- Music and Architecture: from Digital Composition to Physical Artifact
  J. Ham - (2005)
- A Design Checking Tool Based on Aesthetic Properties from Design Theories of Architecture
  CHOO, HOFF, JUNG - (2005)
- Performing Palladio
  Swarts, Economou, Monaghan - (2006)

Volume VI.ii

Readings on Translational Studies

- Transformational Design

  Costas Terzidis -(1989)
- Spatial Forms Generated by Music

  Mirjana Devetakovic Radojevic - (2002)
- Real and Virtual Spaces Generated by Music

  Adrian J. Levy - (2005)
- Translating Urban Environment to Music

  Tomara, Liapi, Parthenios - (2011)
- Plan_B the Architectonics of Sonic Information

  S. Lee & K. Bodt - (2007)
- Music and Architecture: Bonds

  Bessone\/Miro (2007)
- N-Polytope

  Chris Salter - (2012)
- Anisotropia

  Chistoph Klemmt - (2012)
- Three Musical Interpretations of Le Corbusier's Modulor

  Radoslav Zuk - (2013)
- Spatial Aspects in Xenakis' Instrumental Works

  Boris Hofmann - (2005)
- Immersive Strategies in Iannis Xenakis' Polytopes

  Sven Sterken - (2009)