

Designing Sounds and Spaces: Interdisciplinary Rules & Proportions in Generative Stochastic Music and Architecture

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This paper compares stochastic processes used for designing sound and space: an interdisciplinary transference of generative techniques. The mathematical conceptualisation and graphical visualisation by expert architect, Le Corbusier and expert designer and composer, Iannis Xenakis form a single basis applicable to generative systems in two disparate disciplines. Expertise is related to a form of transformational analogy and to designing the grammatical, generative system rather than the artefact itself.

Le Corbusier and Xenakis are considered from two angles: to compare the way in which interdisciplinary and conceptualised design planning is implemented by expert designers; and to examine the potential for generative systems in a multi-disciplinary context. The usefulness of the latter lies in connecting disparate disciplines and as a basis for generative computation spanning discreet design domains, for example multimedia installation design. The comparison also highlights the extent of expert designers' formalisation and conceptualisation that occurs graphically and mathematically before implementation in the chosen design domain. It is interesting that the designers' focus lies in developing the generative system and defining its relation to musical or architectural grammar, rather than in designing the artefact itself.

1. A Generative System Approach

The significance placed on developing the generative system by Xenakis and Le Corbusier corroborates existing evidence of different approaches to designing by novice and expert designers (Kavakli and Gero, 2001; Kokotovich, 2002).

Design grammars or generative systems operate at fundamental macro-levels of idea conception. Shared mathematical, stochastic, probabilistic and serial methodologies for structuring designs exist at this foundational level. This paper examines some examples of stochastic and serial design grammar in works by architect, Le Corbusier, architectural and musical compositions by Iannis Xenakis to identify mathematical and stochastic procedures that traverse two disciplines. The generative process underlying both is a form of transformational analogy. It is the universal

nature of mathematical laws and their relation to natural phenomena that validate these grammatical principles for organising structure at microcosmic and macrocosmic levels of the design strategy. The generative principles provide a method for determining large-scale structural proportions as well as localised, relatively superficial, details. This paper provides some explanation of spatial and multi-dimensional 'architectural' structure applied in musical composition.

Designing space in architecture and in music are both three dimensional practices. While music operates predominantly in the dimensions of pitch/register, duration/rhythm and time, architectural design determines primarily the three geometric dimensions. Further parameters of condition such as colour, dynamic intensity (music) and texture apply to both disciplines and restrictions also moderate stochastic design processes – performability, construction materials, building regulations, gravity, cost, etc.

Stochastic rules of design in both disciplines are informed by rules of mathematics. This potential, utilised by expert designers to achieve transference of generative techniques from discipline to another, relates design thinking across a group of creative, yet structured, fields of design. This paper explores mathematical procedures as a single basis for stochastic design grammar traversing two design disciplines.

Shape (contour), geometry, ratio / proportion and sequence are characteristics from extra-musical practice or scientific disciplines applied to generative systems by Complexist, avant-garde composers. Composers who have applied this way of thinking include: Ian Shanahan, Chris Dench, Brian Ferneyhough, Milton Babbitt, Peter Maxwell Davies, Helmut Lachenmann, Michael Finnissy, Iannis Xenakis, Edgar Varèse and Pierre Boulez.

Compositions by Iannis Xenakis, himself an architect and composer, demonstrate the influence of architectural structure, in particular the serial design concept of his mentor, Le Corbusier, applied to the discipline of musical design. The spatial and geometric relationship between the disciplines of music and architecture highlight their shared generative technique. Xenakis' work also integrates the distribution of graphical information and quasi-genetic tree diagrams onto the spatial topology of the piano keyboard and orchestra, illustrating the significance of abstract (mathematical) conceptualisation and visualisation to design creativity.

Xenakis articulated the mathematical bases for inter-disciplinary grammatical practices in his treatise, *Formalized music: Thought and Mathematics in Composition* (Xenakis, 1971). The architecture of Le Corbusier, alongside whom Xenakis worked as assistant for many years, applies serial proportions as a foundational design grammar. There is correspondence between musical generative systems and the formation of mathematical series, probabilistic theory and algorithms in other design

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disciplines. This paper pursues the notion that stochastic systems and design rules in the field of composition can be considered as a form of design grammar, as presented in 'Observing Musical Composition as a Design Grammar' (Beilharz, 2001).

Xenakis writes: "interdisciplinary hybridization frequently produces superb specimens" (Xenakis, 1971). "My musical, architectural, and visual works are the chips of this mosaic. It is like a net whose variable lattices capture fugitive virtualities [sic] and entwine them in a multitude of ways ... But the profound lesson of such a table [of Coherences] is that any theory or solution given on one level can be assigned to the solution of problems on another level." (Xenakis, 1971). Xenakis articulates the connection with expertise in design: in the transference of a generative technique from one discipline to another.

At the heart of Xenakis' way of thinking is the attitude that solutions in macro-composition on the Families level (programmed stochastic mechanisms) can engender simpler, more powerful new perspectives in the shaping of micro-sounds than the usual trigonometric (periodic) functions. The epitome of an integrated generative system is the way in which the designer relates different granularities of process and applies a pervasive grammar to different style-determining parameters. It is supposed that relational systems at the macro- and micro-levels of design are more typically found in highly conceptualised and formalised work of expert designers than novice designers. Confidence in the generative system is such that the artefact is the outcome of a well-defined generative system. The apparent rapidity with which Frank Lloyd Wright was purportedly able to produce his design for *Fallingwater* (Web), might be explained by his well-refined aesthetic and generative approach, of which the specific design was simply the outcome. The most significant design thinking occurred in the invention and refinement of the generative system.

During his career, Xenakis eventually moved from composed sounds for analogue performance to computer-generated sounds: the only way in which he could accomplish his complex synthesis of hitherto non-existent sounds. Generative Stochasticism applies broadly to the gamut of deterministic, procedurally constructed design including music by Karlheinz Stockhausen, Anton Webern, Pierre Boulez, Milton Babbitt, and Elliott Carter, amongst many. Within the broad definition of stochastic design, serialism, especially integral serialism, is a subset.

Xenakis viewed his musical compositions as the experimental dossier of his design strategies. Xenakis identifies "meta-art" (Xenakis, 1971) as the foundation of "truth" that underpins his design work. Considerable design preparation occurs at the pervasive, objective mathematical level. It might be argued that it is the objectivity of mathematics and its ubiquity in nature that make it the suitable grammatical grounding for generative systems across a range of design disciplines. Xenakis reiterates the long

history of determinism in design practice, from deterministic European Schools of antiquity influenced by Platonic and Pythagorean causality and geometrics to the ubiquity of the Fibonacci Series and the Golden Sequence that is revealed in Pyramid design, Mozart *Sonata Form*, art works of Leonardo Da Vinci, Michelangelo and proportional influences in Mondrian, the Cubists, and Escher. Strict causality was subsequently followed by fertile transformation, facilitated by statistical theories in physics.

Le Corbusier, for whom Xenakis worked for some time as an engineer and architectural assistant, is known for his application of serialism to architecture. His most documented stochastic contribution to generative design was his instigation of a proportional system, *The Modulor* (Boesiger and Girsberger, 1967).

2. Serialism and Stochasticism in music

A subset of (so-called) atonal music composition followed a new path parallel to physical sciences, simultaneously almost absolutely deterministic. Two methodologies for applying statistical procedures to design were in probability theory and polyvalent logic: enrichments or augmentations of the principle of causality. This law is formed on the basis of the law of large numbers that implies an asymptotic evolution towards a stable state, a goal, of *stochos* from which the adjective "stochastic" derives. Every design generated by determinism is more or less pure, the degree affected by the breadth of application and fundamental logic. The designer or composer chooses the parameters and values initially assigned in a stochastic system. Music can be an organisation of elementary operations and relations between sonic entities (Xenakis, 1971). In the words of the composer: "stochastics cannot be carried through without the help of logic – the queen of the sciences, and ... of the arts – or its mathematical form algebra. [It] is also valid for all forms of art (painting, sculpture, architecture, films, etc.)" (p.4-5) (Xenakis, 1971).

The designer or composer reaches the abstract and grammatical roots of a generative system by examining the construction level. To generate structure and purpose, the composer uses a system of causality. The traditional heritage of Functional Harmony – the 300 year tradition of tonal, modal harmony from the time of J.S. Bach onwards – served this purpose. Olivier Messiaen, with his multimodal music, and the Viennese Serialists who mastered logical determinism in atonality through serial pitch organisation, both offered monumental steps towards abstraction of the principles governing structural design and system design in musical composition. This is designing at a strategic or meta- level of the hierarchy, forming recognisable 'style' rather than designing at the (relatively superficial) decorative, literal level. Xenakis explained the necessity of probability with his realisation, in his article, "The Crisis of Serial Music" (Xenakis, 1971), that linear polyphony destroys itself by its very complexity, becoming an unrecognisable, amorphous mass of sound.

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There is contradiction between the polyphonic linear system and the perceived (heard) result. Instead, the significance will be the statistical mean of isolated states. This idea served as Xenakis' bridge to introducing mathematics in music.

If the link seems too arbitrary or abstracted, Xenakis points to another manifestation that is so often cited as a foundational influence in designing: natural events – collision of rain with hard surfaces, the song of cicadas in a summer field. Nature has long been the other informant of design grammars and generative systems – e.g. Fractal Theory, Evolutionary Design, Neural Networks. The correlations between natural phenomena and those mathematical principles applied to design in music and architecture will reveal that the origins are the same. Perhaps it is the fundamental truths, described by mathematics, revealed in natural phenomena and borne out in stochastic design systems, with which we identify. Mass events, such as the sound of a crowd, are both aleatoric and stochastic. The laws of passage from complete order to total disorder in a continuous explosive manner are stochastic laws, a chain of logical reasoning. Continuity may produce either continuous or discontinuous elements. With these principles we start to see the emerging musical phenomena found in Xenakis' composition – cloud formations of multi-event structures, blooms of asynchronous minutiae forming meta-structures, perceived as large events.

Xenakis believed that if *glissandi* (smooth pitch slides, usually on a bowed stringed instrument) were sufficiently long and interlaced, it would be possible to obtain sonic spaces of continuous evolution, equivalent to ruled surfaces in architectural design (Fig.1) (Xenakis, 1971). He first employed this design technique in his composition *Metastasis* (first performed in 1955 in Donaueschingen) and later he used the same principle in his design suggestion to Le Corbusier for the architecture of the Philips Pavilion in Brussels for the World Trade Fair (Fig.2) (1958).

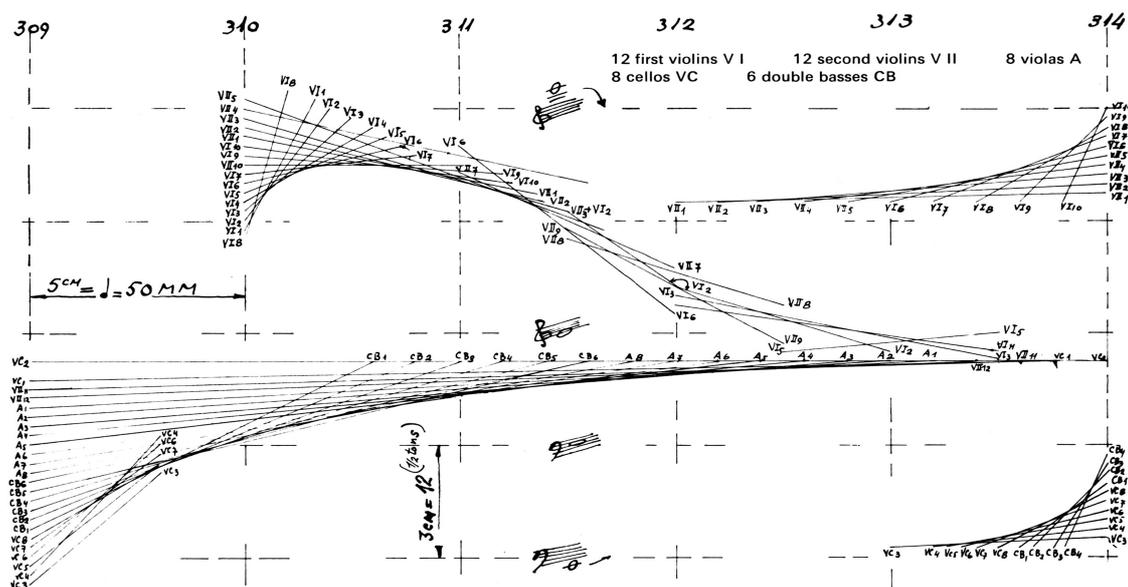


Fig.1. Graphical representation of the *glissandi* pitches in *Metastasis* demonstrating the correlation between the string slide formations in musical pitch and the architecture of the Philips Pavilion, originating in Xenakis' composition and continued in the architecture of the Montreal Pavilion.

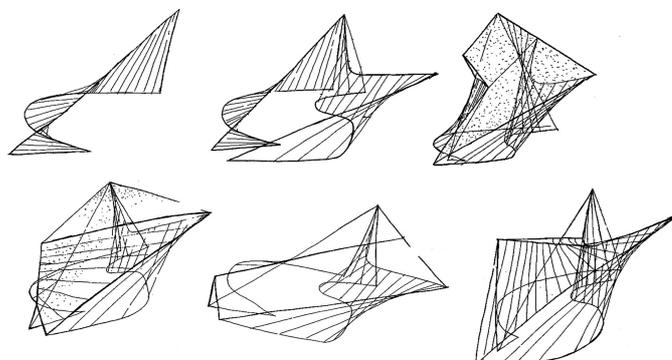


Fig.2. Different stages in the development of the first design of the Philips Pavilion, experimenting with various configurations of conoids to build a shell comprising as few ruled surfaces as possible with varying triangular peaks and hyperbolic paraboloids.

3. Relations of temporal design to spatial design: musical time and proportion derived from mathematical principles

Iannis Xenakis derived sets of grammatical functions that clarified his design choices. These are briefly outlined below. An extended mathematical discussion of their rationale and validity is not the subject of this paper. The illustration demonstrates some transference of probabilistic laws to serial composition.

3.1 Durations

Metrical time can be considered as a straight line and events marked along it equate to events. Space between points represents duration. How are the points and positioning of points chosen?

The following example (Fig.3) gives the probabilities for all possible lengths if one knows the mean number of points placed at random on a straight line. With this information one can deduce the amount of chance included in a choice.

$$P_x = \delta e^{-\delta x} dx$$

Fig.3. Equation in which δ is the linear density of points, and x the length of any segment.

3.2 Clouds of sounds

Defining the intensity-pitch space within a given duration (Fig.4) based on density of a pitch cluster, probability of a particular density occurring in a

given region of the intensity-pitch space may be addressed by Poisson's Law:

$$P_{\mu} = \frac{\mu_0^{\mu}}{\mu!} e^{-\mu_0}$$

Fig.4. Equation from Poisson's Law testing density.

3.3 Intervals of intensity and pitch

Again, probability that a segment (interval of intensity, pitch, etc.) within a segment a , will have a length within γ and $\gamma + d\gamma$ is verifiable (Fig.5):

$$\theta(\gamma) d\gamma = \frac{2}{a} \left(1 - \frac{\gamma}{a}\right) d\gamma$$

Fig.5. Inclusion of intervals of intensity and pitch within a segment.

3.4 Speeds

Speeds, for example of *glissandi* (pitch slides), can be constant, accelerating or decelerating. Distribution of constant speeds is calculated on a basis of density of concurrent mobile sounds. Speeds are mobile entities. The hierarchy is isotropic, i.e. no privilege given to certain directions of motion or register. This attitude produces both symmetry and the mathematical potential to calculate relative frequency of occurrence. To this, Gaussian distribution applies and Xenakis went on to use Boltzmann's kinetic theory of gases to establish the probability of speed. With his metaphor, including sonic "temperature", Xenakis arrives at a sonic compound in which durations do not vary, the mass of pitches is freely modulated, the density of sounds at a given point is constant, the dynamic (intensity) is not varied, *timbre* (tone colour) is constant, and speeds determine the "temperature" and fluctuations. Their distribution is Gaussian (Xenakis, 1971). These generative processes have been applied to sonic parameters by Xenakis but could equally form a generative technique for other design domains.

3.5 Design phases

Applying generative systems applied to design requires significant calculation and graphical representation. This affects the phases of the design process and also integrates the macrocosmic and microcosmic relations of the design system. Here we see a correspondence between Xenakis' process and expert designers who spend a significant proportion of time conceptualising, more than novice designers (Mathias, 1993) and for whom processes of drawing, visualising and re-evaluating designs contributes to the "generation of new information based on previous statements" and ultimately "results in reasoned explanations of problem solutions" (Kokotovich, 2002). Xenakis works through the compositional process in the following sequence: initial (intuitive and provisional) conceptions; definition of sonic entities (assigning instrumentation, sets of

ordered sonic elements, granular formations); definition of transformations (processes, macro-compositional choices of algebraic operations and arrangement in time); micro-composition – detailed fixing of functional and stochastic relations of elements and choice of elements; sequential programming (deriving the pattern of the whole work); implementation calculations; applying the final symbolic result to traditional musical notation; and sonic realisation of the program – either live human interpretation (performance) or computational construction. It can be seen that this highly stochastic approach actually affects the way the designer thinks and works. The graphical representation phase during design is a valuable reasoning process that can invoke further idea generation (Akin and Weinel, 1982). His strategy positions most emphasis on the formative or “pre-compositional” phases of planning and the devising of the grammar and strategy is of much greater significance than its eventual implementation (Beiharz, 2001).

3.6 Different grammatical permutations for different compositions

Examining individual compositions reveals that a grammatical approach based in mathematical probability underpins a large group of works but the individual processes for distinct works are devised on a piece by piece basis.

The work *Stratégie* is an example of a work that follows Xenakis’ macrocosmic design grammar while simultaneously having its own set of specific game rules (Fig.6). Conductors “draw lots” and make tactical choices that feed into the game matrix. These grammatical rules are established to give some arbitrary choices to the conductor (resulting in individual performance renditions) and running permutations like spatial seating of performers on the stage and audience through the game matrix. A tactical game emerges between two conductors, in which one will be the “winning” contestant. This is an interesting combination of Chance and Choice in a stochastically generated composition. There are three matrices employed in *Stratégie*. They are used to provide symmetry as well as advantage and disadvantage in the strategic play on the part of the two conductors. This example demonstrates the notion of progressing between internal and external representations found in expert design (Kimbell, 1991).

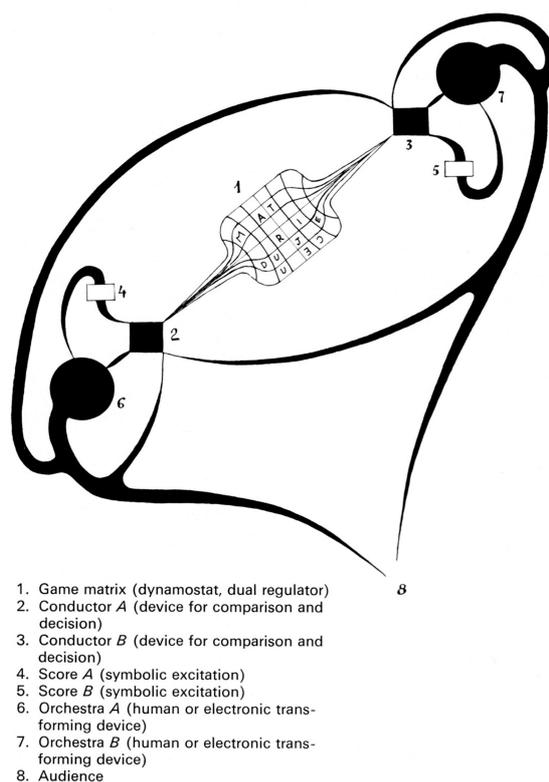


Fig.6. Xenakis' diagram illustrating choices and interplay

3.7 Stochastic music executed by computational process

The treatment of compositions by machines was, in part, a response to necessity as the designer's desired outcome exceeded human capacity for complexity and accuracy. It also illuminated the notion that the design or the grammatical formalisation was the most significant part of the creative process and realisation was execution of design grammars formulated by the composer.

3.8 Symbolic grammatical structures

Symbolic structures in the grammatical rules seem to embody part of the design strategy and the interdisciplinary nature of representing design ideas both mathematically and musically. It was important to Xenakis to represent Boolean expressions and functions graphically, e.g. as Venn diagrams used for the realisation of *Herma* for piano (Fig.7). The graphical representation clearly elucidates the symmetries and economies of the musical structures (Fig.8). The graphic mapping is consistent with findings that sketching and visualisation support creative mental synthesis (Kokotovich, 2002). Graphs summarise the affects of the system on intensities, densities, and silences and it demonstrates the correspondence between values and pitches, thereby showing a higher level overview of the composition. The lower levels are also extrapolated graphically before the composer denotes the artefact in traditional musical notation on a score.

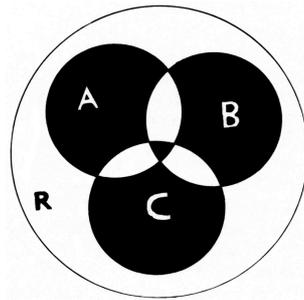


Fig.7. Venn diagram representation of Boolean expressions in *Herma* for piano. The function for three classes, each of which intersects with the other two.

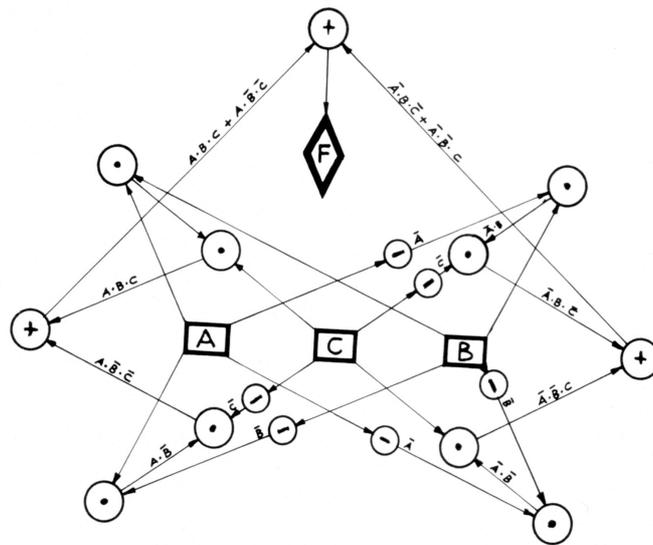


Fig.8. The flowchart of operations. The same function, *F* can be obtained with only ten operations.

3.9 Graphical encoding for macro-structures

Macro-structural encoding shows the greatest correlation between mathematical structures in musical design grammar and generative systems in other disciplines. The micro-structures generate specific values within a cosmic structure (see Fig.9).

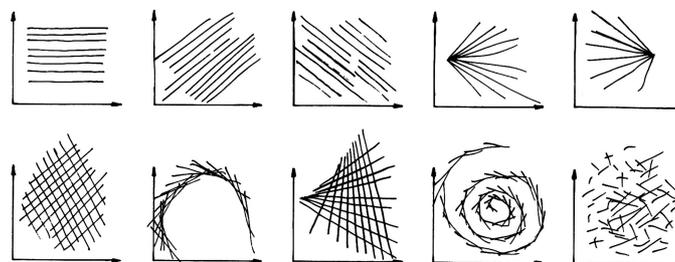


Fig.9. Elementary ruled fields, graphically representing distinctive general qualities of registers, textural density (ensemble scale), intensity, variations of timbre, fluctuations (localised) and degree of disorder.

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Symmetry transformations of a cube are used to generate the hexahedral group isomorphic to the symmetric group (Fig.10). These transformations give rise to the rules for organisation in time.

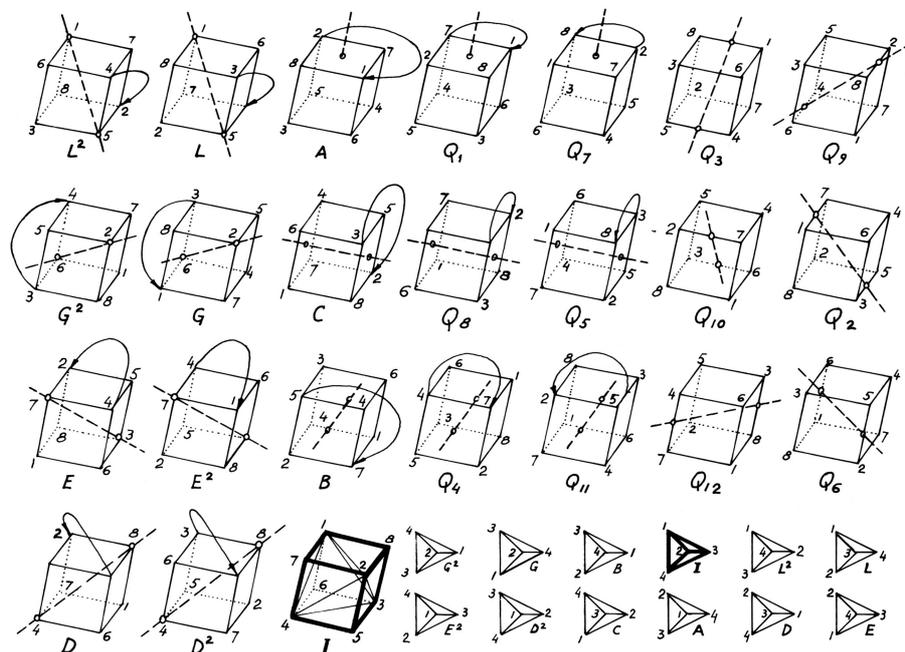


Fig.10. Symmetry transformations of a cube, used to generate the hexahedral group isomorphic to the symmetric group (Xenakis, 1971).

Organisation outside time uses macroscopic sound complexes mapped in different ways: ataxic clouds of sound-points; ordered ascending or descending; ordered not ascending or descending; ordered fields of sliding sounds; interferences in quasi-unison; interferences with accompanying gestures (*pizzicato*). Kinematic sets map various operations (musical) such as plucked sounds, *tremolo*, harmonics across the parameter of pitch. Variations of macroscopic sound complexes are mapped onto products of the vector space of pitch and playing techniques – plucked, bowed, struck, etc. in *Nomos Alpha*.

Xenakis used stochastic processes to express the idea of masses of sound tending towards a mean or a goal such as a stable state (stochastic composition constructed from the principle of indeterminism, defined by the Theory of Probability with standard deviation). *Pithoprakta* undergoes transformations from one unified texture to another, largely by transitions applied to sustained and sliding (*glissando*) pitches connecting a constant mass/density of orchestral texture, the composition of which changes over time (Fig.11). These masses are referred to as 'clouds' by Xenakis.

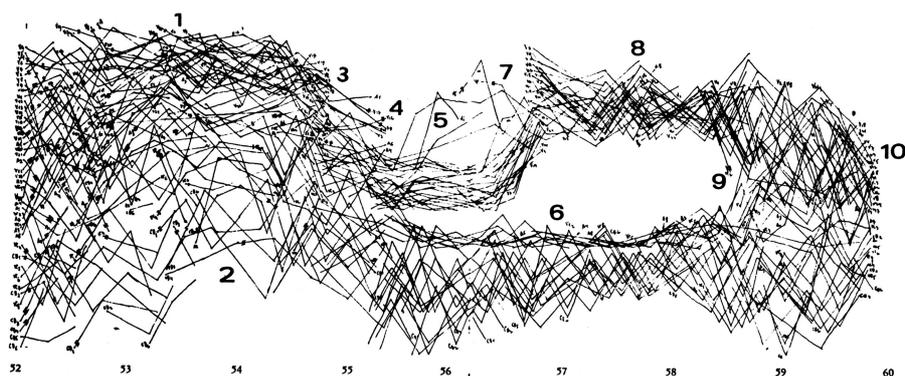


Fig.11. Plotted paths of *glissandi* in *Pithoprakta*. Each line represents a stringed instrument named on the vertical axis using pitch frequency from low to high as *y* values. The horizontal axis represents time. The overall shape bears out symmetries and the 'architecture' of the pitch clusters.

3.10 Graphically denoted organic forms

Without departing from graphical denotation to formulate sound in space, pitch and time, an interesting group of works from the 70s put aside the stochastic process dealing with overall architecture in favour of random 'walks' and arborescences, e.g. *Gmeorh* (1974 - organ), *Noomena* (1974 - orchestra), *N'Shima* (1975 - voices and instruments) and dendritic *Erikthron* (1977). The latter is constructed entirely from *glissandi* and arborescences in fine lines and macro-forms with no interferences, discontinuities or novel formal elements breaking the amassing orchestral lines. These compositions are also concerned with designing the detail of timbral envelopes: colour, tone quality, roughening, coarsening and serrating. Xenakis used stochastic variations of sound pressure directly in his formation of synthesised sound to move away from the normalising influences of the Natural Harmonic Series. This theory is a direct consequence of his stochastic methods in macro-composition where he related probability functions to musical elements by rules of correspondence. "Capricious" and random stochastic functions such as that for Brownian motion produce infinitesimal irregularities and fluctuations of natural sounds and noise.

4. Chance, Chaos and Stochasticism in music

The problem with deterministic stochastic process is obvious: the relevance of its conception hinges on extreme accuracy of realisation only likely in computationally rendered compositions. As Xenakis' complex 'clouds' of sound became more akin to synthetic sound formed by computational algorithms, his musical output did gradually shift to electronic music. Along with Boulez (in IRCAM studio, Paris) and Stockhausen (Frankfurt), Xenakis was one of the first to pioneer early computer music and subsequently to develop these ideas in the U.S.A (CEMAMu). Another problem is justifying the arbitrary choices made by the grammarian in designing his generative system alongside the logical extrapolation of micro-structures. The chance versus accuracy or randomness versus predictability tension affects any generative system

especially if it is implemented computationally, without room for human interference and discretion.

5. Le Corbusier's *Modulor* system of proportions

Le Corbusier (1910-1965) developed various methodologies to systematise house construction, e.g. he devised structural frameworks that operated independently from the floor plan itself in a form he called the "Standardised Framework" (Boesiger and Girsberger, 1967) around which construction of exterior walls took place. He standardised methods of fabrication and material attachments as an attempt to address the problem of rapid reconstruction required after the First World War. He further evolved a modular system of construction (Fig.12) consisting of rectangular and square cells in geometric proportions that could be assembled in various formations without detracting from individual initiative of design.

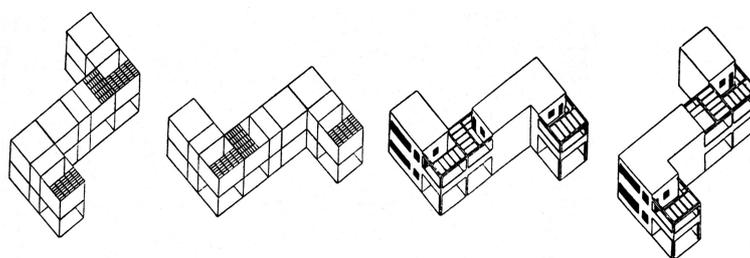


Fig.12. Configurations of the modular 'Standardised House'.

Le Corbusier developed some grammatical principles, the 'Five Points of New Architecture' that could be applied across a range of design scenarios or to generative systems. Not yet stochastic, he was moving towards a systematised and ordered protocol for designing. These rules included use of columns, roof-gardens, and free plan design not reliant on strictures of the load-bearing wall made possible by the introduction of reinforced concrete, long windows, and free façades.

With *The Modulor*, Le Corbusier intended to define an harmonic measure on a human scale that was applicable to architecture and mechanics (Boesiger and Girsberger, 1967; Evenson, 1970; Web). The system, like any grammatical implication, relies on the applicant. The fundamental concept is a set of ratios proportional to digits, limbs and intervallic divisions of human proportion that form a harmonic and agreeable system by which to divide up space. There is a clear resemblance of this notion to Golden Sequence and Divine Proportions, which have been ubiquitous in architecture, maths, science, aesthetics and music for many centuries. His idea was well supported by the Congress on the Divine Proportion and by artists and mathematicians in Milan, even though Le Corbusier's sequence is much more clearly symmetrical than the Fibonacci Sequence, for instance (as illustrated in the numerical values of Fig.13). While systematic on one level, Le Corbusier's serial system resulted in disorientation and impracticality because it revolved around proportions of a 183cm tall European male build –his system is inflexible and

fundamentally flawed. On the other hand, like Xenakis' systems, he created a stochastic and potentially generative approach. Permutations of his initial series rapidly generated alternative measures for proportion, as described in his red series and blues series (Fig.14).

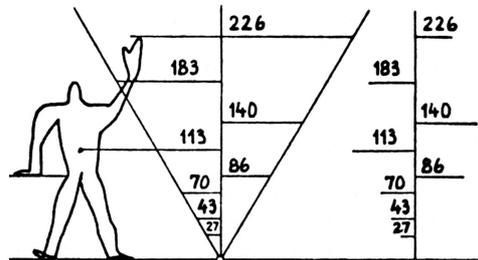


Fig.13. The grid provides three measures related by the Golden Rule (Boesiger and Girsberger, 1967) ϕ 113, 70, 43cm ($43 + 70 = 113$ or $113 - 70 = 43$). In addition, $113 + 70 = 183$, $113 + 70 + 43 = 226$. These three measures (113, 183, 226) characterise the space occupied by a man of 6ft.

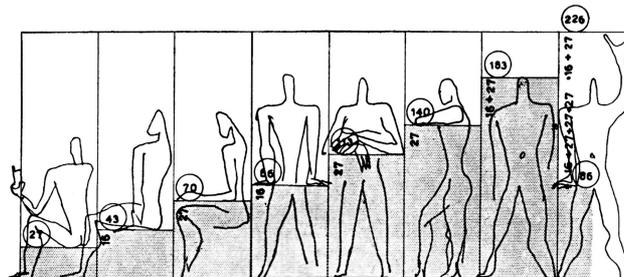


Fig.14. Application of the Golden Rule to the measure 113 leads to the Serie Rouge: 4-6-10-16-27-43-70-113-183-296, etc. Application of the Golden Rule to the measure 226 provides a second series, Serie Bleue: 13-20-33-53-86-140-226-366-592, etc. Some of these values or measures are characteristically connected to human stature.

Le Corbusier used his system extensively in the Unité d'Habitation de Marseille and other buildings.

6. Xenakis' architectural applications of Stochastic grammars and Le Corbusier's *Modulor* proportions

Xenakis was extremely fortunate to commence his post-war employment as an engineer working with architect, Le Corbusier, surrounded by a team of architects and engineers. Le Corbusier himself had spent formative years as a painter as well as an architect. From his painterly years, his aesthetic emphasised pure, geometric volumes – cubes, cylinders, spheres – and his basic elements of composition were "choice of surface, geometric locations, regulation lines, modules, values, colour" (Corbusier and Ozenfant, 1920). Proportion was to be his unifying agent and systematic use of proportion throughout canvas and architectural design later. Le Corbusier's own interdisciplinary experience and his predisposition to serial and systematic design formed the perfect

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environment for the stochastic dialectic to incubate. Le Corbusier invested considerable interest in studying ancient Greek architecture to find Golden Sequence occurrences. The series of Le Corbusier's *Modulor* system came from the idea that mathematical proportions could be found in human form, man-made artefacts and in a diversity of natural phenomena. It is this natural occurrence of mathematical bases for stochastic design that provides a ubiquitous pervasiveness relevant to all disciplines. Given the propensity for artists and designers to model nature, it is hardly surprising that the mathematical explanations form substantive platforms for stochastic laws.

Xenakis used Le Corbusier's method to unify plans contributed by different architects and in the unification of the Unité d'Habitation de Marseille, with which he was involved. Here the value of the serial technique is its versatility for connecting and unifying disparate designs by individual expert architects, rather than as a generative tool. As a methodology for unifying discreet elements, Xenakis recognised its potential in musical composition. Xenakis finally discovered a solution to Le Corbusier's perennial problem of exposed bearing beams in free-standing concrete buildings. He calculated that the concrete was inherently adequately strong to withstand weight and pressure without the beams. In earning Le Corbusier's respect, Xenakis' concepts began to be implemented architecturally. Collaborating with Bernard Lefaille (Matossian, 1986), a technician and architect with a strong grasp of mathematics, Xenakis checked plans for Le Corbusier and studied musical composition concurrently with Olivier Messiaen, a patriarch of new systems in composition.

It is important to note that the new approach to massed sound established in *Metastasis* preceded Xenakis' architectural experiments in paraboloid roof structures. In architecture, Xenakis observed a formal principle that posed an alternative to an organic model. Le Corbusier combined heterogeneous elements and quasi-independent parts into a single building design, deploying formal elements and materials according to his intuition, assured of cohesive proportions serving as the chief unifying factor.

Xenakis extended Le Corbusier's Indian inspiration of transparent building walls in his development of the façade of the monastery overlooking Eveux (Fig.15), the famous *Pans de verre ondulatoire* or, in Le Corbusier's words, 'musical panes of glass' (Fig.16) (Corbusier, 1958). Xenakis used the *Modulor* to obtain a progression of rectangles on the same height, of differing widths, arranged in rows of changing densities to give the asymmetrical appearance. He extended the idea further to different floors, likening his design to musical polyphony. "Xenakis had solved an architectural problem with an essentially musical solution, a detailed polyrhythmic study with light and shade as the dynamic range" (Matossian, 1986). This was no arbitrary solution, however, rather the aesthetic success rests with the underpinning sequence and it is the

argument of this paper that it is the foundational proportional and mathematical bases that allow stochastic and serial process to operate fluently and in an interdisciplinary way.

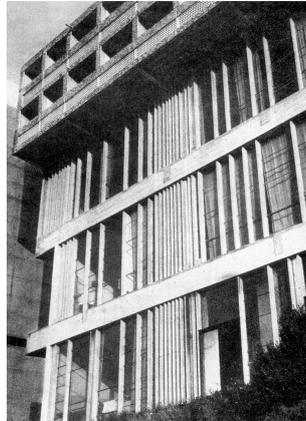


Fig.15. The West façade of the Convent of la Tourette (Matossian, 1986).

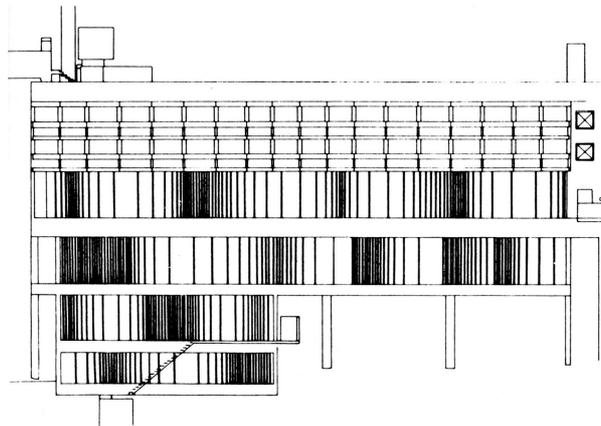


Fig.16. Couvent de St Marie de la Tourette: West elevation with undulating 'musical' screening of glass designed by Xenakis using Le Corbusier's *Modulor* system (Matossian, 1986).

Although it was Le Corbusier who took the public credit, it was Xenakis who entirely conceived the form and mathematical expression for the Philips Pavilion.

Inspired by the shape formations of his Light and Sound shows, the Polytopes, combining electronic music and choreographed light movements of laser beams, Xenakis planned the web of steel cables that was to support 1200 lights for the French Pavilion of the Montreal Exposition of 1967, meanwhile composing his first spatial music, *Terretektorh*.

In interview (Matossian, 1977) Xenakis stated:

"I found that problems in architecture were the same as in music.
One thing I learned from architecture which is different from the

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way musicians work is to consider the overall shape of the composition, the way you see a building or town. Instead of starting from a detail, like a [musical] theme, and building up the whole thing with rules, you have the whole in mind and think about the details and the elements and, of course, the proportions. That was a useful mode of thinking.”

7. Conclusion

Two major trends are examined here in the architectural and compositional work of Xenakis, the composition of Boulez and the architecture of Le Corbusier: stochastic and serial generative systems of design. It is neither the natural phenomena nor the stochastic processes alone that lead to underlying aesthetic satisfaction and relevance of processes to more than one design discipline. It is the foundational mathematical integrity that substantiates the stochastic and proportional laws applied in the thinking of the composers and architects discussed. The transference of generative techniques from one discipline to another illuminates the potential for integrating multimedia designs. Re-examination of the design process illuminates a significant pre-composition or pre-architectural conceptualisation phase of fundamental, transferable and inter-disciplinary organisation that occurs in the approach taken by two expert designers in two distinctive design domains. The designers have found strategic value and structural unity in their foundational serialisation. It is interesting that essential design emphasis falls on the creation of a generative system, rather than on its output and that the product becomes an artefact of an expert generative system. The ingredients of structural integrity are more basic or pure than elements and materials particular to the domain. Foundational design grammars based on stochastic, mathematical reason traverse design disciplines. Probabilistic and proportional systems are further recognised and reinforced in human perception because the mathematical laws informing stochastic practice are based in familiar natural phenomena. The works of these designers validate stochastic generative systems for designing, traversing two disciplines.

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Glossary

- Serialism – Ordering in rows, primarily refers to sequential organisation of pitch. The prime row can be interpolated through a standard group of permutations – inversion, transposition, retrograde, retrograde inversion and reordered according to matrices.
- Integral Serialism – Ordering of multiple parameters or categorisations of elements, e.g. sequential organisation of pitch, rhythmic durations, tone colours, articulations/attacks, dynamic intensity.
- *Glissandi* – smooth, usually constant speed pitch slides including all microtonal intervals between standard tunings. Also *portamento*.
- Aleatory – randomness, disorder, can be used to describe 'chance' events or chance music.
- *Pizzicato* – plucked tones on a stringed instrument (e.g. plucking a violin that might otherwise be bowed).
- *Timbre* – tone colour, sonority. Different instruments have inherent *timbre* and distinctive *timbres* can be achieved by using different playing techniques on a single instrument, e.g. plucked and bowed strings, muted or unstopped horns. Different registration also lends subtle changes to an instrument's tone colour or *timbre*, e.g. the different sounding low and high registers (*tessitura*) in a human voice or a 'cello.

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