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Architecture as Music: A personal journey through time and space

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My journey started in the City of London, where I found a building, the Cheesegrater, that generated harmony, pattern, discord, repetition and silence. It inspired me to produce a piece of Visual Music, Citirama, expressing the relationship between architecture and music. The success of the piece during presentations and performances has now led me to formulate a considered view on how music and architecture can be found to coexist: how our new understanding of the concept of space/time can bring an art form concerned primarily in mapping sound in time closer to a form focused on what we experience in moving through space. From the Cheesegrater, my wanderings led me to a building, in Berlin, where the emotions of music have been conveyed in purely architectural terms and to another structure, in Brussels, which, during its short life, offered a total architectural/musical experience in time and space. I conclude that, over the centuries, Western developments in architecture and music have tended to obscure their common roots in Ancient Greece. Although Pythagorean mathematical links still persist, its through our new 21st century awareness of how the human brain causes us to see and hear that, once again, architecture and music will be able to sing in unison.

Architecture. Visual music. Pythagoras. Philips Pavilion. Parthenon. Auditory & visual scene analysis.

1. THE JOURNEY BEGINS

As abstract arts, architecture and music share a common aim to create harmony, weave patterns, define spaces, move in time, promote feelings, touch the senses and act as an outward expression of an artist's aspirations. Such a statement must, in itself, provoke discord; surely, these aims cannot be achieved in equal measure by both art forms. Can architecture move in time? Can music define space? Remember that Pythagoras ascertained that the sounds of the anvil he heard in that blacksmith's shop over 2,500 years ago underpinned rules that governed not only the measures of sound but, also, the proportion of spaces and, ever since, the physics of sound has defined the rules by which architects design space. Alberti and Le Corbusier might have devoted much time to honing the proportional systems that underlay their constructions but, always, the rules remained close to those that produce concordant sound. Of course, over time, people's perception of concordant sound changes; each generation of composers will strike new chords to excite, or possibly to aggravate, the ear of the listener. Similarly, architects will produce new forms, influenced by technological advances that embrace and contain space in unexpected ways. But what composers and architects have in common, now, is a shared understanding of the relationship between space and time. Whether or not this knowledge has been gleaned from a close study of Einstein's theory, it has entered, nevertheless, the consciousness of all those who seek seriously to express the spirit of the times in their art.

This synchronicity of sound and space was brought home to me, recently, by one particular building in the City of London. Its architects had not set out to produce architecture with a musical agenda but music can happen anyway when a building generates its own harmony, pattern, discord, repetition and silence. Rhythms of ebb and flow can be sensed in a structure without there being any preconceived intention, on the part of its creators, to endow a building with musical meaning. I found these qualities in the Leadenhall Building (known colloquially as the 'Cheesegrater'). It was a realisation that came gradually during a visit to the site, before the building was finished, and during discussion with one of the two project architects involved. No doubt, he was somewhat surprised when, at the conclusion of our meeting, I announced that I saw the Cheesegrater as the basis for producing a piece of Visual Music expressing the relationship between architecture and music.

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Nevertheless, Rogers + Stirk + Harbour supported my idea from the beginning and have remained enthusiastic ever since. The resulting piece, Citirama, has been shown at the Melbourne International Animation Festival and I've performed it live at the 2016 Brighton Digital Festival and at Intetain held last year in Madeira (Trickett 2017).

2. CITIRAMA: VISUAL MUSIC CELEBRATING THE CHEESEGRATER

In producing Citirama, my objectives, as ever in my Visual Music, were to explore an idea and communicate it through a process that combined moving visual imagery with musical performance on solo clarinet. Now, enough time has elapsed for me to take a retrospective look at what I produced so as to formulate a considered view on how music and architecture can be found to coexist: how our new understanding of the concept of space/time can bring an art form concerned primarily in mapping sound in time closer to a form focused on what we experience in moving through space. In this paper I aim to show how the three movements of Citirama can throw some light, each in its own way, on a subject that not only deserves some further analytical inquiry but, also, continues to fascinate and engage our senses.

Figure 1: *The Cheesegrater invites people inside rather than presenting a closed façade to the world.*

As with all Richard Rogers' buildings, the Cheesegrater makes its mark by revealing structure, services and circulation routes on the outside; the workings of the building are not hidden but, instead, they become the means of expressing its nature and function. It invites people inside rather than presenting a closed façade to the world (Figure 1). All in all, the character of the building offers a rich source of pattern making material. But what are these patterns? First and foremost, what I see is a series of *leitmotifs*. (I'm making use of the musical connotations of this term quite deliberately.) Sometimes these are small details. At other times they are whole elevations or complete spaces. But always they serve to capture a design language that produces architecture of exceptional quality. In Citirama, I've taken delight in joining the patterns of architecture with the rhythms of music and, conversely, joining the rhythms of music with the patterns of architecture.

3. CITIRAMA: FIRST MOVEMENT

In the first movement, I introduce a set of repeat patterns, all derived from the building's *leitmotifs*, which I then project on to the slanting façade of the Cheesegrater (Figure 2). (It is this slanting façade that has given rise to the building's nickname.) Of course, my giant animated display could never happen in reality; the building is 45 floors high (currently, the tallest in the City of London) so, inevitably, my projections must remain a computer simulation. But this doesn't prevent them presenting a continually moving graphic interpretation of the *leitmotifs* where the rhythms of music join with those of architecture to promote a close interchange between the two art forms. In Citirama, the visual and aural elements of the performance are given equal prominence.

Figure 2: *The First Movement of Citirama reveals patterns projected on to the Cheesegrater's façade.*

3.1 Architecture as music

My projections on the Cheesegrater are an outward expression of the building's intrinsic musicality but where such a quality is extrinsic, as in Daniel Libeskind's Jewish Museum, Berlin, it can be allowed to speak (or sing) for itself. The Museum's geometry, based on distortions of the Star of David, produces not just a zig-zag spatial experience internally but, also, a graphic expression of the Museum's musical score on its external elevations (Figure 3). Together they elicit a strong emotional response from visitors, which exemplifies Libeskind's belief that the way architecture is produced and received can be very similar to music – a fact that is less surprising when you know that, before becoming an architect, he was a high-calibre performing musician. As Libeskind comments:

> I see architecture as musical. When I look at buildings, I don't just see them as planes, two-dimensional or three-dimensional projections. I see them as a musical composition. I hear them

> acoustically. Architecture is a world of relationships that is very, very close to my experience as a performing musician. My own response is that architecture, the way it is produced and received, is very similar to music (Libeskind 2008).

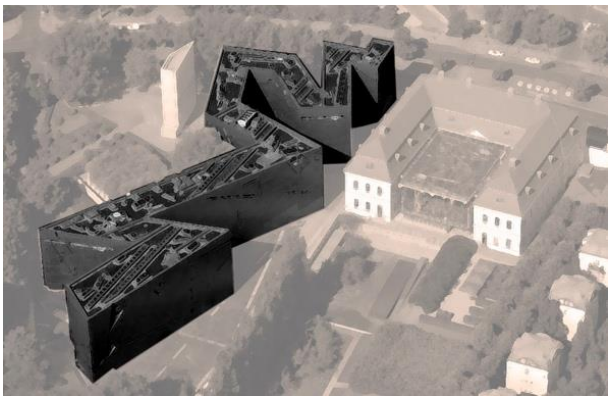

Figure 3: *Aerial view of the Jewish Museum, Berlin. The zig-zag geometry of Daniel Libeskind's building is based on distortions of the Star of David.*

Libeskind had practised long and hard to achieve his success in Berlin. The building itself was 13 years in the making and in a previous occupation as Head of the Architecture Department at Cranbrook Academy of Art in Bloomfied, Michigan, Libeskind had produced a series of studies, Chamber Works, where musical notation appeared to be transcribed into 'spatial music' – a kaleidoscopic collection of lines and symbols that represent the structure of sound (Figure 4) (Libeskind 1983). They were not fantasy projects but architectural explorations. As Libeskind states:

> They have embedded themselves in my own experience, and I use them continuously within my present architectural work. In fact, these are the scores through which I orchestrate present commissions (Libeskind 2008).

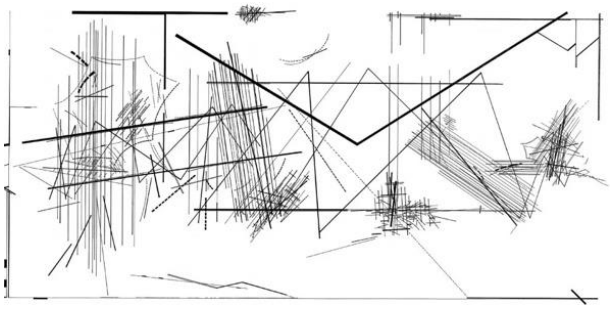

Figure 4: *Chamber Work by Daniel Libeskind – a kaleidoscopic collection of lines and symbols.*

The viewer can sense that Chamber Works' abstract forms are musical without being able to figure out specific lines of notation attributable to particular instruments. But when Libeskind says that a specific musical work was endemic to the design of the Museum not only do we know this to be true but we feel its effect when we are there, experiencing the full emotional impact of the spaces. We can sense that the Void, which cuts across the whole of the building, was the architect's response to an episode in Arnold Schoenberg's *Moses and Aaron* – an incomplete opera that ends prematurely with *'o Wort, du Wort'* no longer sung but spoken to convey Moses, reduced almost to silence, as he laments his inability to lead the people to the promised land. Libeskind's skill in conveying the emotions of melancholy, sadness and desolation, using only the techniques of architecture, is extraordinary and almost unique.

3.2 Using the devices of graphic design to create music

The devices of graphic design can be used not only to reflect and interpret music but, also, to create it. An example can be found in the work of Cornelius Cardew who, in his short life, experienced a remarkable musical *volte face.* As a student, he introduced *Boulez's Structures* to the Royal Academy of Music, London, and later, in the late1950s, he became Karlheinz Stockhausen's assistant preparing the score for *Carre* – a project that caused him to fall under the spell of John Cage. As a result, Cardew abandoned formal notation in favour of improvisation where *the subtlest interplay on the physical level can throw into high relief some of the mystery of being alive.* In 1965 he joined a group of four musicians in London to perform a pure form of improvisation operating without any formal system or limitation. About this experience, Cardew has stated:

> Informal 'sound' has a power over our emotional responses that formal 'music' does not, in that it acts subliminally rather than at a cultural level (Cardew 1971).

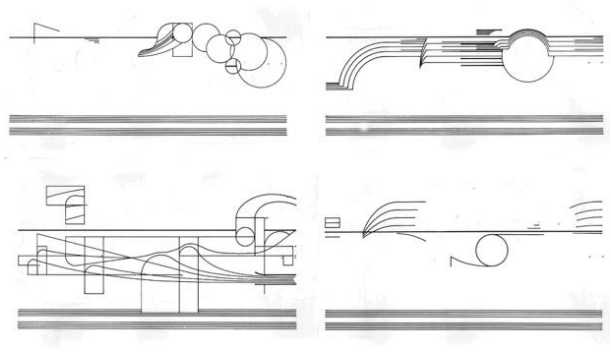

Figure 5: *Four pages from Treatise – a graphic score created by Cornelius Cardew.*

Cardew's increasing anathema towards formal notation systems led him to produce *Treatise,* which consists of 193 pages of graphic score with no systematic instructions as to its interpretation and only the barest hints to indicate that the interpretation is to be musical (Figure 5) (Hall 2017).

He believed that, ideally, *Treatise* should be played by musical innocents who have a certain facility in reading graphics. The performances that were most rewarding, at least to his ear, were by people who had acquired a visual education, escaped a musical education but had nevertheless become musicians. Cardew felt that the musical and the real worlds are one; musicality is a dimension of perfectly ordinary reality. He never expressed a view on the ordinary reality of architecture although the quality of his graphic scores suggest, to me, that in addition to his well-trained ear he possessed an equally finely-tuned eye. If ever he could have visited the Jewish Museum, I have no doubt that he would have fully recognised the Museum's musicality as being something well beyond the ordinary. In my imagination, too, I see him raising his eyes skywards to witness the graphic fantasies on the Cheesegrater's façade play out their rhythmic dance; is it just possible, I wonder, that their improvisatory impact, as revealed in the first movement of Citirama, would have exerted some *power over his emotional response*?

4. THE MUSIC OF CITIRAMA

Before turning to the second movement of Citirama and the spatial patterns it weaves, I should explain my choice of music for the work. Sonatina for Solo Clarinet by Richard Rodney Bennett is improvisatory without being an improvisation. Like his saxophone concerto written for Stan Getz, it can be described as combining jazz harmonies with the composer's own free-flowing serial technique. It is constantly changing rhythms give the piece a compelling musical momentum that expresses Richard Rodney Bennett's versatility in a wide range of modes and styles. Interestingly, as a student, he was contemporary with Cornelius Cardew; it was as a pair of virtuoso pianists that, together, they gave the performance of Boulez's Structures that I've already mentioned as being particularly significant in Cardew's early development. Richard Rodney Bennett spent further formative years working with Boulez in Paris where he embraced serialism but eventually decided to find his own way by fusing lyricism, jazz and classical conventions within a musical language that was to find success in over 50 film scores. The choice of his Sonatina for Solo Clarinet as the musical component of Citirama gives me an opportunity to demonstrate the composer's prodigious musicality in a piece of Visual Music which I can only hope he would have enjoyed.

5. CITIRAMA: SECOND MOVEMENT

Moving on now to the Second Movement of Citirama, you will see that I create a series of reverse explosions as fragmented components of the building's *leitmotifs* gradually come together or spin apart to reveal the architectural elements from which they're derived (Figure 6). It is in taking a retrospective look at these visual events, that I'm reminded of a comment made by Iannis Xenakis with regard to equivalent explosions in sound:

> A complex sound may be imaged as a multi-coloured firework in which each point of light appears and instantaneously disappears against a black sky. But in this firework there would be such a quantity of points of light organised in such a way that their rapid and teeming succession would create forms and spirals, slowly unfolding or, conversely, brief explosions setting the whole sky aflame (Xenakis 1992).

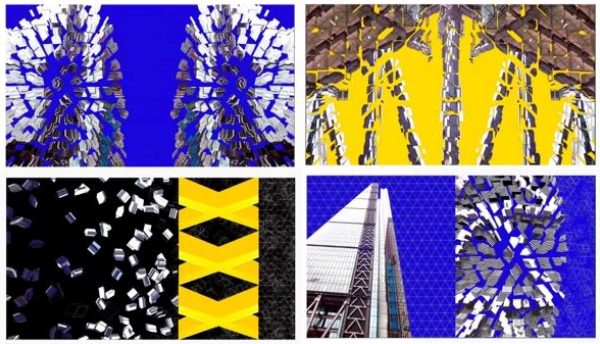

Figure 6: *The second movement of Citirama reveals a series of explosions as the 'leitmotifs' spin apart.*

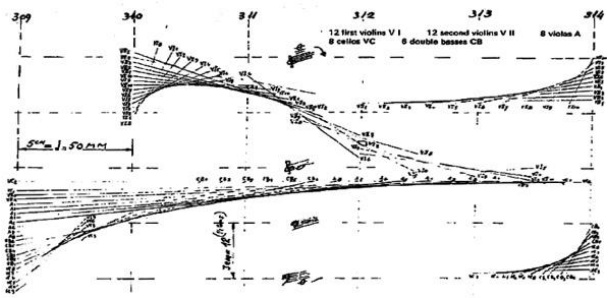

Figure 7: *Bars 309 – 314 from Metastasis by Iannis Xenakis showing string 'glissandi'.*

Xenakis made this comment in connection with his own Stochastic Music, born after he had both denounced polyphony and demonstrated the contradictions of serial music. In their place he proposed *a world of sound masses, vast groups of sound-events, clouds, and galaxies governed by new characteristics such as density, degrees of order, and rate of change.* In *Metastasis,* his first piece for full orchestra, Xenakis developed his Stochastic ideas in the form of *glissandi;* sonic spaces of continuous evolution derived from long and interlaced sounds produced by dragging the bow across the strings of a violin, cello, viola or double bass (Figure 7). Further, he made a visual representation of *glissandi* by drawing a set of incremental straight lines to produce forms which, eventually, led to designs for the Philips Pavilion at the Brussels World's Fair, 1958 (Sterken 2001)

(Figure 8). As an architect working in the atelier of Le Corbusier, he was given free rein to experiment with space, time and music – a rare opportunity which, to my knowledge, hasn't been repeated since.

5.1 The Philips Pavilion

Xenakis has been described as an 'architect of music'. In designing the Philips Pavilion, he combined the mathematics of Le Corbusier's proportional scale, *Modulor,* based on the Fibonacci series, with his own research on hyperbolic conoids to create a causal chain of ideas where 'music and architecture could be bound together in intimate connection'. With an interior shape that resembled the stomach of a cow, Xenakis's design involved creating tensile structures of steel cables strung from steel posts at the ends of the 'tent' to form his hyperbolic conoids. The Pavilion's complex shape meant that it couldn't be built as a conventional poured concrete structure so the final solution was to create a system of precast concrete panels hung in tension from the steel cables. The resulting *Poem Electrique* combined architecture, film, light and music in a total experience made to function in time and space. Musically, Xenakis was responsible for composing a transitional piece heard by audiences before they were enveloped in the main space of light and sound pulsing to a score by Edgar Varese, a composer who Le Corbusier had chosen in preference to Benjamin Britten or Aaron Copland.

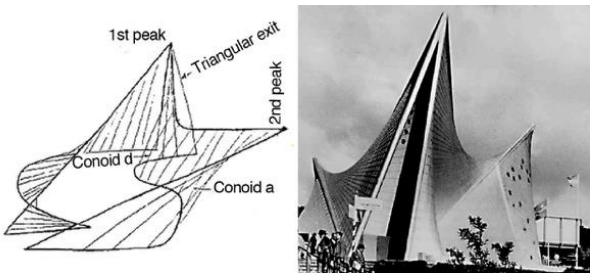

Figure 8: *A visual representation of 'glissandi' produced forms that led, eventually, to the design of the Philips Pavilion at the Brussels World's Fair.*

The young Xenakis must have been less than pleased with his secondary musical role at the Philips Pavilion but, still, he had gained hugely from the opportunities it had given him to experiment with space and time – a subject which remained at the forefront of his thinking ever after.

5.2 A journey back in time

It was as an architectural student that I visited the Brussels World's Fair, in 1958, to experience, at first hand, the all enveloping sights and sounds of the *Poem Electrique*. It is only through a process of full immersion in a work of architecture or a piece of music that its impact can be seen, felt and heard; there's no way that an adequate evaluation can be made from plans, photographs or hearsay. My memory of some events may have faded but I still have an awareness of what it was like to be inside Xenakis's hyperbolic conoids; it is an experience that can never be repeated but it did provide, for me, some sort of measure by which the musicality, or otherwise, of a building could be assessed. Remember that those responsible for creating 'architecture which sings' may not have set out with any such intention but, nevertheless, the result can still succeed in touching the auditory senses of the building's visitors or inhabitants; the visual harmony that results from a satisfactory piece of architecture can, to quote Le Corbusier, make people serene or gay (sic), as can music.

What is the link between architecture and music? It was a problem shared by one classical Greek, Xenakis, living in the 20th century and Ancient Greeks living over 2,500 years ago. For Pythagoras, finding a link was just part of a much bigger question embracing mathematics and the universe. As a young man, he undertook a journey to Babylon and Egypt, the birthplaces of mathematics, and returned with the conviction that all of creation exists in a perfect harmony of numbers; he divined that the orbits of the planets play musical notes whose pitch is dictated both by the speed of their movement and their distance from the sun. He wasn't far wrong in his conjecture because physicists now believe that the universe is fundamentally wave-like and can be represented by a temporal evolution of sound wave forms (Alexander 2017).

In matters of measurement, too, Pythagoras was responsible not only for his famous theorem, $a^2 + b^2 = h^2$, but, also, for the Western music scale. He picked out, from the repeated hitting of a blacksmith's hammers on an anvil, sound vibrations, or notes, that were pleasing to the ear. As the hammers used by the blacksmith differed from each other by ratios of one half, he was able to deduce the interval of an octave and, then, by applying this same principle to vibrating strings with lengths that were successively divided in halves, Pythagoras produced the notes of a major scale. It is a very similar set of intervals that produce the Fibonacci Series and, thereby, the proportions of the Golden Mean – a series of precise comparative measurements used by both ancient Greeks and Egyptians in designing their buildings and monuments. Even more extraordinary is the fact that the elucidation of the principles of the Golden Mean is attributed to Theano, wife of Pythagoras, who ran the Pythagorean school in southern Italy, in the late 6th century BC, following her husband's death. As a paramount source of knowledge and learning, the Pythagoreans (husband and wife) established indelible links between architecture and music that, ever since, have remained viable and immutable. They produced measures and rules that

have underpinned Western adventures in both the creation of visual 'harmony' in the spaces within and between buildings and the aural 'tensions' between the pitch of notes in a musical composition as they unfold in time.

6. CITIRAMA: THIRD MOVEMENT

There is a further important consideration relating to the measure of time, which forms the focus of Citirama's third movement. Here, a series of quick change *collage* confound the eye as each image, showing a different arrangement of the Cheesegrater's *leitmotifs,* appear and disappear in time with the constantly changing rhythms of Richard Rodney Bennett's music (Figure 9). As ever, the Greeks have a word for it – *rhythmos* – movement, fluctuation or variation marked by the regular recurrence or natural flow of related elements. To illustrate this concept, which is common to both architecture and music, I will turn again to my early life odyssey. My journey to the Brussels World's exhibition, in 1958, didn't end there but continued, via discursions and vicissitudes, to the steps of the Parthenon. For many architects this building, and the Acropolis on which it is sited, is a place of pilgrimage. For me, the allure of its architecture was prefaced by visits to the Elgin Marbles, in the British Museum, where the sense of movement conveyed by these relief sculptures from the frieze of the Parthenon is a cause of wonder. They sent out a strong signal that I must find out for myself whether or not their birthplace, on the hill of the Acropolis, would exert a similar impact.

Figure 9: *The third movement reveals a series of quick-change 'collage' with each one formed from a different assembly of the Cheesgrater's 'leitmotifs'.*

6.1 The pull of the Parthenon

Many before me have felt the pull of the Parthenon. Almost more than any other observer, Le Corbusier, in his *Towards a New Architecture,* regarded it as an exemplar of almost every quality he admired in architecture; he devoted far more words (and illustrations) to the Parthenon's features than to any of his other references. He found in the Parthenon *a work* that *rings within us in time with a universe whose laws we obey, recognise and respect*. He described a site, which is surprisingly uneven and *out of square,* as a place where visitors experience vistas stretching from the mountains to the sea (Figure 10). The buildings themselves, the Parthenon, the Erechtheum, the Propylea and the small temple Athena Nike, are arranged asymmetrically with the relative distances between buildings creating a variety of rhythms:

> ...rhythms apparent to the eye and clear in their relationship to one another. And these rhythms are at the very root of human activities. They resound in man by an organic inevitability, the same fine inevitability which causes the tracing out of the Golden Section (Mean) by children, old men, savages and the learned (Le Corbusier 1986).

Figure 10: *Aerial view of the Acropolis. In his visit of 1911 Le Corbusier saw, at the Parthenon, a system which appeared to satisfy a spiritual order through the pursuit of ingenious and harmonious relations.*

Le Corbusier was one of the foremost advocates for applying the Golden Mean to art and architecture. His appreciation of the Pythagorean definition of harmony achieved by numbers led, eventually, to his own Modulor. which aimed to provide a harmonic set of human scale measures, universally applicable to architecture (Le Corbusier 1958). In bringing to the process of design the means of fixing the fundamental geometry of the work, Le Corbusier provided an 'assurance against capriciousness'. No doubt, it was his visit to the Acropolis, early in life, that led him to set in motion his inquiry into regulatory lines and measurement. He had seen, at the Parthenon, a system that appeared to satisfy a spiritual order through the pursuit of *ingenious and harmonious relations:*

> It confers on the work the quality of rhythm; the choice of a regulatory line is one of the decisive moments of inspiration (Le Corbusier 1986).

The Parthenon was the apogee of a long process of development and constant refinement. Sophisti-cated techniques were used to combat the optical illusion that a large-scale building appears to be curved. To create the illusion of straightness, the columns lean over slightly inwards, a device that also makes the Parthenon appear lighter than its heavy marble construction would suggest. Also, the stylobate, or floor of the temple, is not exactly flat but rises slightly in the centre. The columns have an

entasis (i.e.. a slight widening towards the half way point in their height) and the four corner columns are almost imperceptibly wider than other columns. The combination of these refinements makes the Parthenon seem perfectly straight, symmetrically in harmony and gives the building a sense of vibrancy. As Le Corbusier comments:

> If we are brought up short by the Parthenon, it is because a chord inside us is struck when we see it. It is an impact that can't be felt in other Doric temples which, by comparison, seen static and fail to raise the emotions (Le Corbusier 1986).

7. FORWARDS TO WHERE I STARTED

My visit to the Parthenon, all those years ago, didn't disappoint; sitting on the steps, in the company of Richard Rogers and Paul Koralek, watching the sun go down, was a life-changing experience. Today it would be difficult to recreate the same sense of a *work ringing within us in time with a universe whose laws we obey* because of on-going restoration work which has caused the monuments to be hidden behind a plethora of scaffolding. But, back in 1958, for all three of us at various stages of becoming architects, the Pentelic marble cast its magic spell. The fact that it is Richard Rogers' Cheesegrater that has caused me to set out on this current, vicarious journey through space and time seems both apt and inevitable.

Our reaction to some Doric temples, which fail to ignite the emotions or senses, is only too familiar; it applies to the vast majority of buildings, past and present. But I don't subscribe to the idea that any particular style of architecture lacks the potential to strike a chord within us. The spore of the Modernist movement may have produced many bland, formulaic constructions but the exceptions, where visual harmony is combined with the *rhythmos* and natural flow of repetitive elements, prove the rule. When visual harmony is created, the tensions of music can happen, as I found to be the case in the Cheesegrater where my journey started. From this point, my wanderings have led me to a building, in Berlin, where the emotions of music have been conveyed in purely architectural terms and to another structure, in Brussels, which, during its short life, offered a total architectural/musical experience in time and space. But these examples are few and far between; it seems that, over the centuries, Western developments in architecture and music have tended to obscure their common roots in Ancient Greece. Pythagorean mathematical links persist and the universe remains as musical as ever (Alexander 2017) so it is not impossible that a new coming together could be achieved, influenced primarily by our new 21st century awareness of how the complexities of the human brain cause us to see and hear. It is through science that architecture and music, once again, will be able to sing in unison.

8. THE SCIENCE OF AUDITORY AND VISUAL SCENE ANALYSIS

How do the myriad of sights and sounds processed by the brain succeed in conjuring up an impression of a piece of music or work of architecture? It is a subject of considerable current concern for neuroscientists who, succinctly, have coined the term Auditory and Visual Scene Analysis to embrace the extraordinarily complex process by which we see and hear (Kondo et al. 2017). The unravelling of the mysteries of the human brain provides one of the great challenges in science today. Here, in this paper, I can only hint at the experiments and insights, which together are beginning to throw some light on our methods of auditory and visual perception.

Figure 11: *The brain's neural mechanisms analyse the contribution of multiple 'snapshots' to achieve an invariant representation of a scene.*

I will turn first to the subject of Visual Scene Analysis. Visual scenes (which embrace buildings) consist of a complex array of reflected light from objects and surfaces that impinge on our retinae and, thereby, stimulate neural signals to the brain's visual cortex. Although the sensation of seeing occurs extremely rapidly and is seemingly effortless, the visual input is highly complex and dynamic, changing with each fixation as we move our eyes. The features of a scene, its spatial layouts, boundaries and textures, are somehow combined seamlessly into a coherent overall picture. It is known that the process involves the brain's pathways and neural mechanisms bringing together multiple 'snapshots' to form an invariant representation of a scene (or building); the separate properties of a scene are 'recognised' by breaking them down into their basic shapes and patterns. It is the entry of these patterns into the brain's short-term memory that causes the automatic activation of specific matches that might exist in the long-term memory. This process of recognising patterns allows us to predict results and expect what's

coming. When I think of it, I must have applied a system of Visual Scene Analysis during my visits to the Cheesegrater; no doubt, my brain was engaged in a process of pattern recognition in defining the building's *leitmotifs* (Figure 11).

Pattern recognition is again the key to the way we hear – i.e., our systems of Auditory Scene Analysis. When listening to a tune for the first time, the recurring nature of the music's note clusters allows the listener to recognise features such as the tune's time, pitch and rhythm. It is when established patterns are broken that the excitement of listening increases and a problem-solving opportunity arises. At this point, the brain may activate its long-term memory to reference material and additional stimulation stored there and, as in Visual Scene Analysis, it is the entry of this further information into the auditory short-term memory that enables the brain to solve problems by reconstructing all the musical features of the tune into a perceptual whole. The longer the listener is denied an expected pattern, the greater the emotional arousal when the pattern returns. Neuroscientists now believe that music engages the brain regions connected to motor actions, emotions and creativity. Also, when watching or hearing music being played, neurons associated with the muscles needed for playing an instrument fire; they act as 'mirror' neurons which light up when non-musicians as well as musicians listen to a piece.

8.1 The Global Conscious Workspace

Auditory and Visual Scene Analysis reveals how our brains interpret information, interact with it and act upon it. Many specialist neurons are involved in processing what we see and hear; the human brain has something like 100 billion nerve cells each having about 10,000 inputs (dendrites) form other neurons and only a few outputs (axon terminals). Small assemblies of brain cells are networked together in clusters with each neuron performing a specialised function according to instructions encoded in its DNA, its history and chemical influences from other tissues. A large proportion of these tissues are unconscious; there is no centralised command that tells neurons what to do; just as each cell in the body is controlled by its own molecular code, the adaptive networks of the brain are controlled by their own aims and contexts (Baars 1997). The result is a 'global workspace' where conscious contents appear to be disseminated globally to a great multitude of networks throughout the brain that are unconscious (Figure 12). It is this consciousness network, including the auditory and visual cortices, that creates access to the knowledge sources of the brain (contained in the long-term memory). The concept of the global workspace makes consciousness comprehensible!

How does the global conscious workspace hypothesis fit with brain anatomy and physiology? Neuroscientists now believe that during conscious tasks, neurons contributing to the global workspace enter into a coherent self-sustained activation pattern in spite of their spatial separation; they are tightly connected through long axons (and dendrites). Varying concepts of the global conscious workspace are still at the conjectural stage but it is possible to envisage a diagrammatic structure where distinct areas of activity are linked in to a global workspace, which is characterised by massive connectivity. This structure would account for the way auditory inputs generate motor activity (like dancing) and the fact that, in our efforts to understand the world around us, every visual signal has an auditory counterpart. By this means architecture and music are fused inevitably together in our brains; it is a state of enforced separation, as it occurs so often in today's world, which must be regarded as unnatural.

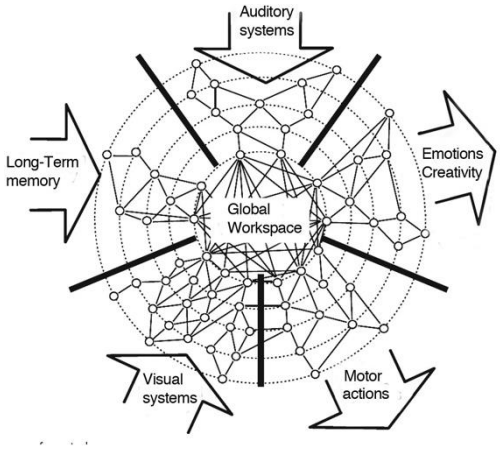

Figure 12: *The massive connectivity of the brain's Global Conscious Workspace (Dehaene et al. 2011)*

9. CONCLUDING THOUGHTS

In this paper, I've pointed to a few examples that have avoided the unnaturalness of separation. But it is still a comparatively rare event to find both the auditory and visual senses engaged to maximum effect in one and the same building. Usually, examples of 'musical' architecture whose spaces we can explore over time are not the same as those that enable us to listen, though time, to the live unwinding of a musical composition. To demand this degree of synchronicity would require that a composer writing a symphony and an architect designing a symphonic hall would need to have not only a shared intellectual concern with the mathematics of sound and space but, also, an equal ability to produce results that engage with the emotions and feelings of audiences. But, maybe, just occasionally, a symphonic hall can be as musical as a symphony. From my own experience of Frank Gehry's Walt Disney Concert

Hall, I'm prepared to say that, on the right night, it is a place where both art forms can achieve a successful symbiosis (Figure 13). Gehry's playing with titanium shapes (derived from the mathematics of aerospace design) has enabled him to produce a Xenakis-like instrument, resonating in time and space, where '*architecture and music are bound together in intimate connection'.*

Figure 13: *Architecture and music can achieve a successful symbiosis as at Frank Gehry's Walt Disney Concert Hall. Los Angeles.*

As science reveals, links between architecture and music are not only mathematical but also biological – our brains are wired that way. This fact helps to explain why, for Daniel Libeskind, his early Chamber Works became the source of his later architecture. Their imagery doesn't look like architecture (or music) but they do seem to represent a gathering together of the shapes (lines, dashes, dots etc.) that can be recognised individually by function-specific neurons in the visual cortex. What, at first glance, appears to be an extremely recondite architectural source document no doubt takes on new meaning through its exposure to many other areas of brain activity, motor, auditory and visual, within the brain's global conscious workspace. So, too, we can now understand why Cornelius Cardew's graphic score for Treatise can be successfully recognised as music by non-musicians. Without expert knowledge, these are the people who have retained open access to the biological links between the visual and auditory landscape. As the advantages of such non-specialisation become increasingly apparent, I can foresee a time, in the future, when the laws of physics and mathematics, common to both architecture and music, will need to be supplemented by an equally valid scientific stance which embraces the biological basis of people's emotional response to both art forms.

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