Generative Logic in Digital Design

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This exploration of early-stage, architectural design pedagogy is in essence, a record of an ongoing transformation underway in architecture, from its practice in the art of geometry of space to its practice in the art of geometry of space-time. A selected series of student experiments, from 1992 to the present, illustrate a progression in architectural theory, from Pythagorean concepts of mathematics and geometry, to the symbolic representation of space and non-linear time in film. The dimensional expansion of space, from xyz to xyz+t (time), represents a tactical and strategic opportunity to incorporate multisensory design variables in architectural practice, as well as in its pedagogy.

Keywords. generative; process; derivative; logic; systemic.

Generative Space

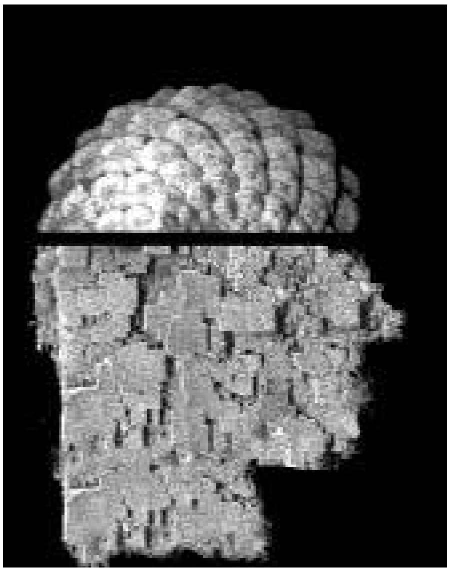
In the 1980's and 1990's, Computer Aided Design automated the symbolic, geometric representation of space, and it did so through the application of principles of modularity, iteration, and recursion. Coincidentally, this created an opportunity for the digital designer to bypass the intended management functions of CAD, representation and validation, and instead to expanded its potential application of recursive and derivative design principles. For instance, Corbusier's "Modular Man," the 20th century's most identifiable architectural icon, addressed principles of self-similarity and proportion; the computer effortlessly and transparently applied these mathematical and geometric representations of modularity. Similarly, Frank Lloyd Wright's "organic" architecture, one of the 20th century's most identifiable architectural principles, was unburdened of its complex and laborious analytical requirements; its generative potential in recursive and iterative principles, became readily addressable.

Time Geometry

Two additional design considerations emerged from this study of geometric progression and generative principles: 1. Time emerged as a dimensional design variable, described by the geometry xyz+t; much as film incorporates nonlinear symbolic content as the message carrier, architectural design is capable of employing nonrepresentational, symbolic means as its message carrier. The multi-dimensional design requirements of xyz+t create an opportunity for a multisensory design interface. 2. Once this dimensional variable is available, sound is addressable. The periodic construction of sound diagrams, as in musical scores, creates an opportunity for a common interface and the simultaneous development of vision and sound in a coordinated multisensory design process.

Precedent

"Architecture depends on order arrangement, eurythmy, symmetry, propriety and economy." - Vitruvius (1st century B.C.)



Ancient Greeks attributed beauty to harmonious principles of nature, a reflection of the greater universe, and applied these principles in music, philosophy, and architecture. Consequently, generative principles infused the proportioning systems of column design, building construction, and even anthropomorphic embellishment. The Pythagorean, mathematical approach "…leads to the use of a constant: a module. It is the module – appropriate to each and every building - that makes it possible to obtain eurhythmia … In expressing a higher reality, they turn the temple into the material realization of divine truth (Stierlin, 1997)."

Rome appropriated principles of proportional modularity, expanded its application with enhanced engineering capabilities, and improved construction management systems. The harmonic engineering solution of tiered and modulated stone arches in the 19BC Pont du Gard aqueduct reflects a significant advance in implementation. Further improvements in generative design capabilities followed in the curvilinear and modulated construction of the Coliseum c. 80AD. In these and other civic structures, the inherent beauty of the arch, its use in proportional modularity, and the application of advanced engineering concepts defined a standard of beauty and function that resonates through time.

Figure 1. 21st Century Man, by author.

Sacred Architecture

The first four hundred years of the new millennium A.D. witnessed the final advance, then gradual disintegration of the civic infrastructure of the Roman Empire; simultaneously, Christianity subsumed existing cultural values and mores. 800 years of theocratic adaptations, primarily of Roman precedent, transpired before a fully transformed Christian architecture was perfected. "In the Cathedral of Chartres the architect has realized the cosmological order of luminosity and proportion to the exclusion of all other architectural motifs and with a perfection never achieved before. Light transfigures and orders the compositions in the stained-glass windows.... perfect proportion, harmonizes all elements of the building (Simson, 1988)." The cathedral operated as a transcendental device according to the harmonic ratios of a divine universe with "God as its architect (Simson, 1988)." The device activated at consecration in perpetuum, on behalf of penitents as a device of salvation.

St. Augustine (354-430A.D.) prescribed design principles for sacred architecture. This knowledge was required to construct the Cathedral, an instrument of divine intervention operating at the intersection of the temporal and spiritual world. The consecration of architecture of sacred proportions activated the harmonic synchronization between otherwise imperceptible realms. St. Augustine organized music, architecture, geometry, proportion, and sacred numbers into theologically sound generative systems of “perfect ratios” “…the source of all aesthetic perfection.” Augustine’s unyielding and restrictive rules of harmonics and proportions provided the foundation for development of a spiritual device constructed on earth – “…rendering it a place in which favours are more graciously granted by God (Pontificale Romanum).” (http://www.newadvent.org/cathen/04276a.htm: May 2003).

Secular Architecture

The Industrial Revolution signalled a significant shift in the concepts of building and design; the division of labour and the specialization of function began an inexorable transition away from the single harmonic reflection of a divine universe. In architecture, design principles reverted to the secular proportioning systems of the pre-Christian era. Sacred principles in architecture gave way to the profane values of humanism, science, and finance – to the great consternation of the Catholic hierarchy. Throughout the 17th, 18th and 19th centuries, secular design failed to achieve stylistic consensus despite rapid technological advances; until the emergence of Modernism, design expression found safety in atavistic reference to prior styles.

It was Einstein’s momentous theories on relativity (1905) that redefined the mechanics of the universe and all that preceded it – in art, it created a foundation for Modernism. Corbusier, an architect of extraordinary intellect and talent, arrived at precisely the right time to exploit Einstein’s revolutionary concepts. “Just as relativity theory overthrew the absolute status of space and time, the cubism of Georges Braque and Picasso dethroned perspective in art (Miller, 2001).”

Space-Time Architecture

Corbusier needed to reintegrate time into architecture – the expediency of productivity of the Industrial Revolution had negated the value of time in architecture. In response, Corbusier developed cubist techniques to symbolically represent multidimensional aspects of space-time in art, “I painted my first picture at the age of thirty-one, in the fall of 1918 (Corbusier).” Picasso, along with Braque, founded cubist expression in 1907, “Picasso and Einstein believed that art and science are means for exploring worlds beyond perception, beyond appearance (Miller, 2001).”

Drawing and paintings in the New World of Space (Corbusier, 1948) reflect techniques developed by Corbusier so that architecture could “take possession of space.” Corbusier cagily avoided crediting Einstein, Picasso and Braque, except for oblique reference to “[Those who] spoke of the fourth dimension with intuition and clairvoyance.” While in the cause of Corbusier, “A life devoted to art, and especially to a search after harmony, has enabled me in turn, to observe the same phenomena through the practice of three arts: architecture, sculpture and painting (Corbusier, 1948).”

Corbusier placed man at the centre of his design universe, “We pause, struck by such interrelation in nature, and we gaze, moved by this harmonious orchestration of space, and we realize that we are looking at the reflection of light.” Corbusier’s invention of the Modulor was a significant contribution to design implementation of his theories.

Modularization and Harmonics

The Modulor is a harmonic proportioning tool used to relate design to human scale. “A lifetime concerned with the play of proportion has led to a discovery which unites, in a single mathematical combination, numbers and the human figure. The harmony recaptured by the Modulor would be without salt if it were exclusively mathematical. Happily, it is in intimate accord with man. Based on the golden mean, which is found in the proportions of the human body, it establishes an essential bond between the pure mathematical event and the determining factor of the building field - to construct a shelter for the body of man (1948)." "The Modulor is a work tool, and as such it is a companion to the compass and the pencil (1948)." The Modulor is in essence a secularized adaptation of the 12th century Fibonacci harmonic constant, a codification of ancient principles of design.

Pedagogy

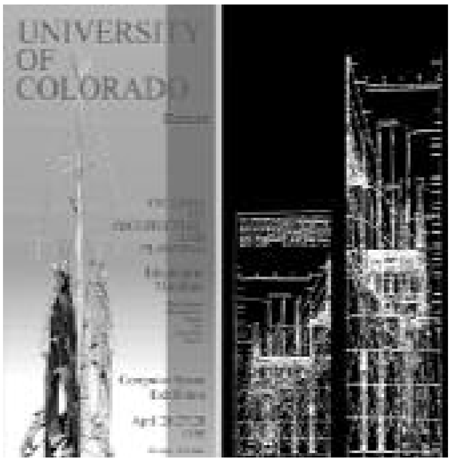


Figure 2. Joe Hosek (1995), Caesariano (1521).

"Eurythmy, the harmony of proportion in architecture, is the "result of well applied symmetry." – Vitruvius

"The only proposition that can be verified – that is, proved true – are those concerning 'closed' systems, based on pure mathematic and logic. Natural systems are open: our knowledge of them is partial, approximate, at best (Horgan, 1995)." In this related discussion of artificial life, natural systems like architecture deal with approximate knowledge and require open logical systems; CAD however operates in a closed logical system. The student's design process must account for this design discrepancy. Computer Aided Design programs readily simulate "closed" generative processes through blocks and x-references. Repeatable block references assume properties of residing layers; each entity assumes a local and world origin (xyz), unique scale, rotation, and orientation. "Scaling laws reveal the fundamental property of phenomena, namely self-similarity - repeating in time and/or space - which substantially simplifies the mathematical model-

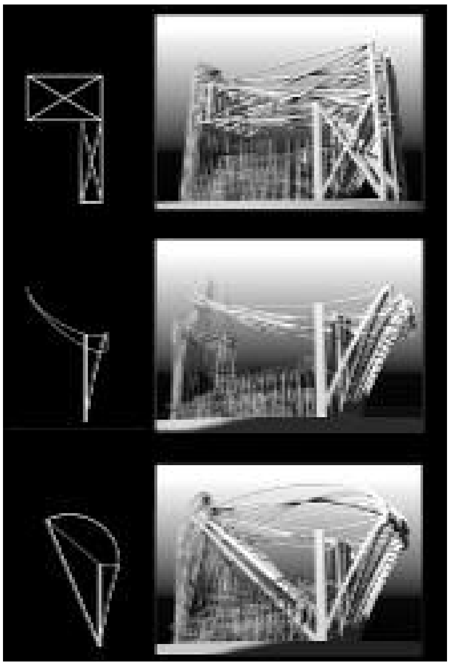


Figure 3. Robin Morrison,generative substitution (1995).

ling of the phenomena themselves (Isaakovich, 1996)."

Fundamentals of Generative Geometry

Case study 1. [Fig.3] illustrates a single element block substitution in a closed design system.

1. Generative Processes: The geometric substitution of one block instance, systemically redefines all referenced structures and spaces.

2. Software: Repeatable Autocad blocks were scaled, arrayed, copied, rotated, and mirrored, then rendered in 3D Studio.

3. Hypothesis: If space is a derivative of a fundamental code played out on a repetitive stage, what is the potential for the systemic development of generative forms in architectural space?

The concept of placement and substitution is a primary consideration in this digital design. It is through this iterative development in the composition process that it is possible to refine design. I refer to this as the DNA of design space, since the design process is 'alive'. A change to any of the parts systemically and simultaneously affects all structure and space in an organic response. A break in this chain results in the end of the generative logic in the design process (Flanagan, 1997).

In an application of case study #1 [Fig. 4], intersecting blocks are edited to accommodate intersecting building conditions.

Fundamentals of Generative Imagery

Rules of grammar are essential in the composition and expression of form. The illustration [Fig 5] from Walter Crane's 1904 Line and Form demonstrates two drawing methods, one oval and the other rectangular. "The real use of the method is to assist the student to get a grasp of the relation of the masses of a figure and a sense of structure in drawing (Crane, 1904)." By incorporating time into Crane's argument, Cubism and its many variants find structure.

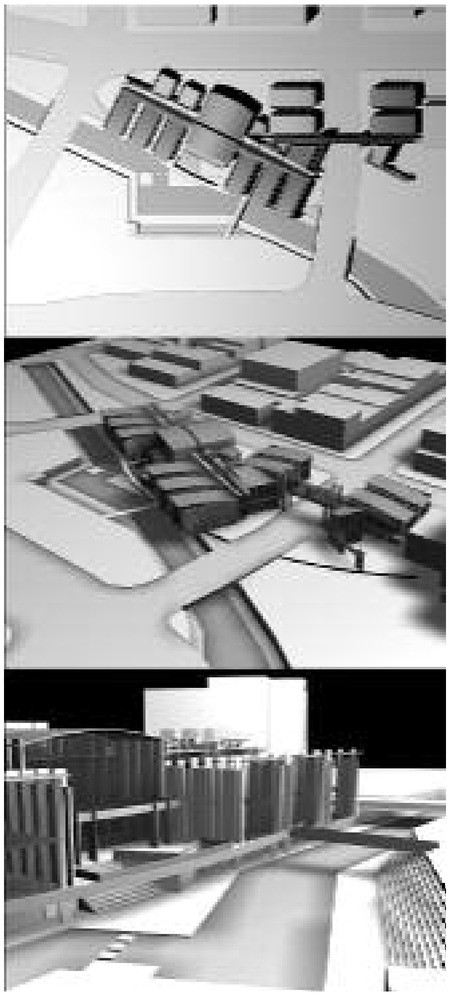


Figure 4. Ta-Yuan Lee, 1 block generative design (1995).

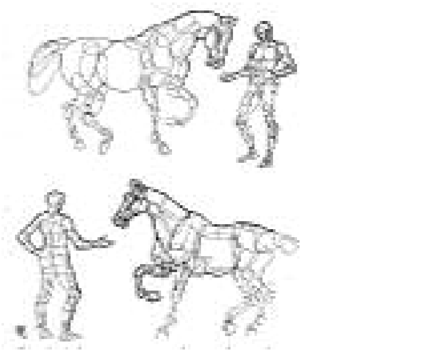


Figure 5. Drawing Methods (Crane, 1904).

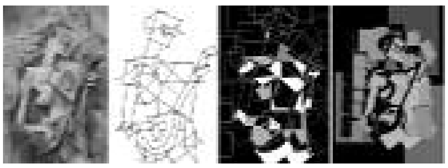


Figure 6. Pablo Picasso's Girl with a Mandolin (1910), Painting Design Analysis by Miranda Karli (2000).

Case study 2. [Fig 6] is a translation of Picasso's Girl with a Mandolin. The sketch is the basis of the Autocad design diagram.

1. Generative Process: Scaled variants of repeated blocks represent the structure and space in Picasso's painting

2. The model was constructed in Autocad, rendered in 3D Studio MAX, and the animated Memory Diagram was composed in Adobe Premiere.

3. Hypothesis: If Eddington 1929 statement that "geometry of the world is now considered to include time as well as space," how might Picasso's time-space theories be applied in architecture?

Case study 3. [Fig. 7] begins with the scanned drawing of a Frank Lloyd Wright floor plan; two graphic components were selected, converted into block elements, then constructed according to "organic" principles (Flanagan, 1998).

1. Generative Process: Two components are selected from the Wright plan, and constructed as blocks in Autocad. The generative composition applies Wright's organic principles in structure and space.

2. Software: same as previous, without animation.

3. Hypothesis: According to Wright, "As originally used in architecture, organic means part-to whole-as-whole-is-to-part. So entity as integral is what is really meant by the word organic (Wright, 1953)." If true, would the application of generative rules of construction be capable of simulating organic form?

Space is often a derivative of a fundamental repetitive code. At every scale, micro to macro,

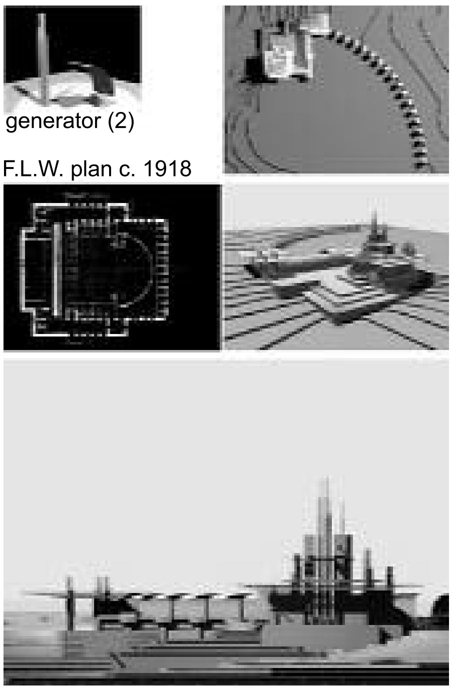


Figure 7. Experiment in organic principles, Frank Lloyd Wright's 1918 Theatre Plan,Clay Colvig 2-block design experiment (1995).

the universe as we understand it is composed of self-repeating and self-generating structure. In the inorganic world, the crystal is the consequence of generative order; in the organic world, DNA is the generative code of life. The above, is an alternate version of a Frank Lloyd Wright design constructed from generative rules in Autocad.

Fundamentals of Generative

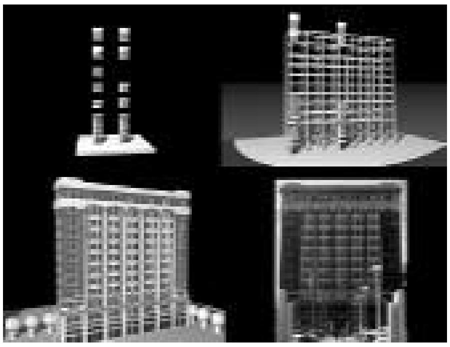


Figure 8. façade design analysis, Roberttino Limandibhratha (1996).

Manufacture

Case study 4. [Fig. 8] is a façade design analysis of an early 20th century office building; rules of analysis are established, block elements identified, and then the proof is constructed.

1. Generative Process: Unique graphic elements (9) are identified in the photograph and translated into block elements, then a computer model is constructed as a proof of the design analysis.

2. Software: Same as previous.

3. Hypothesis: Is it possible to apply the generative rules of construction, used in textiles, to analyse, design, and construct architecture? After all, both are products of the Industrial Revolution.

Facade analysis employs Lowest Common Design Denominator, LCDD (Flanagan, 1997). It is a process of reductive identification and re-composition: 1. Identify, notate and remove symmetry at the building and component level. 2. Identify, notate and remove repetition at the building and component level. 3. Unwrap or unroll curvilinear and non-planer components and apply rule one and two. Note that this system interprets design

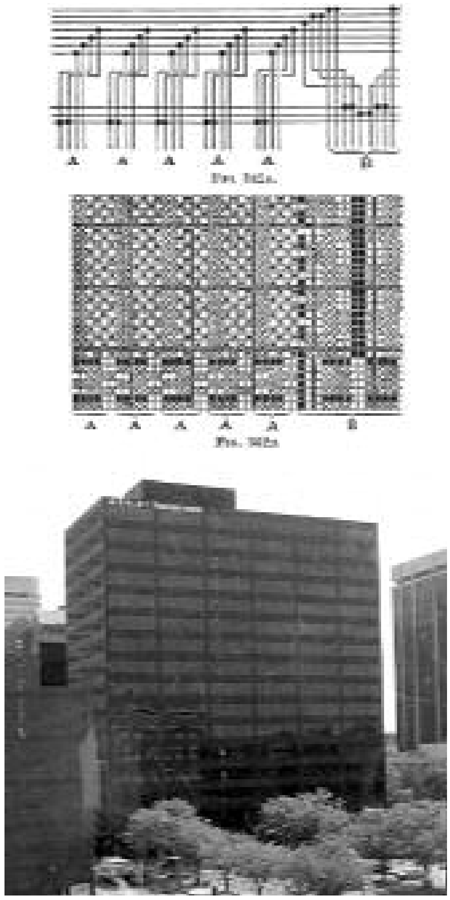


Figure 9. Comparison of healding draft (top, 1921), the generative weaving diagram for the textile pattern (middle), and a 1970's era modernist office building façade (bottom).

by way of projection. 4. Identify, notate and remove any item that repeats at any scale. Mastery of the dynamic link re-establishes design management control of the architecture.

"As will be observed from the healding draft [Fig. 9], the whip threads in A work in pairs with the standard threads, but in B three whip threads intertwine with two stationary threads (Beaumont, 1921)." International style architecture of the Modernist era reflects its unadorned, functional philosophy. The functional aesthetic is reminis-

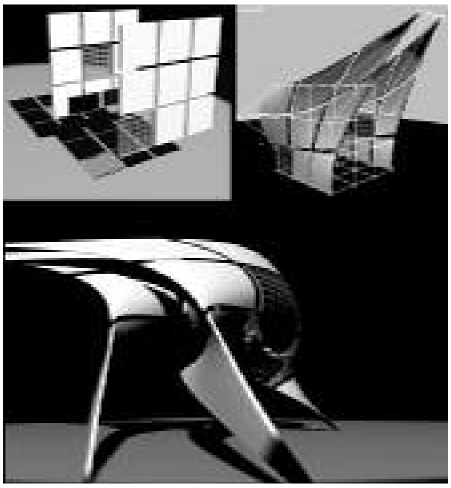


Figure 10. Force modifiers transform modular geometric panels; Author (1998).

cent of earlier textile design and manufacturing processes.

Case study 5. [Fig. 10] is a study in complex form generation through the application of force modifies. Force modifiers create a real-time design interface - the architect manipulates 'machine intelligence.' Predefining engineering characteristics allow for the standardization of the manufacturing process.

1. Generative Process: Force modifiers are globally applied to grouped reference elements (9 above).

2. Software: Reference elements in Studio MAX are manipulated with force modifier (FFD), then rendered.

3. Hypothesis: Since the computer is capable of simulating complex mathematical forms, is it possible to simulate real time design that is compatible with its future manufacturing process?

The performance characteristics of the standardized plates are predetermined at the modular level, including thermal properties, photovoltaic potential, costs, environmental impact, and structural integrity. The exoskeletal assemblage of structure and the skin acts as one; arrayed plates are flexed, warped, and bent. The benefit of this approach is that design means and methods are coincident with design aesthetics (design before method).

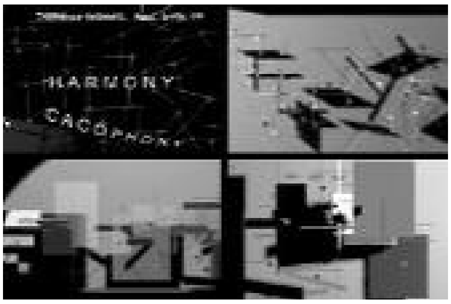


Figure 11. Memory Diagram: text in conflict (sketch) by Stephanie Gerber (2002).

Fundamentals of Generative Space-Time

Case study 6. A Memory Diagram (Flanagan, 2001) is derived from the symbolic, graphic negotiation of text [Fig. 11]. "Harmony and Cacophony," represent the conflict inherent between words and their meanings. The grammar of a partially expanded symbolic diagram is developed; the symbolic composition is constructed along a timeline, including sketches, words, drawings, diagrams, and sound.

1. Generative Process: A sketch (line drawing) negotiates the symbolic conflict inherent between words. Scaled combinations of Autocad blocks re-represent “Harmony & Cacophony” as a symbolic diagram. Sound textures and paces the media composition, reinforcing its message. - Stephanie Gerber, 2002.

2. Software: Diagrams are constructed in Autocad R2000 of blocks; they are arrayed, copied, rotated, mirrored, and scaled. The composition is rendered in 3D Studio MAX and animated in Adobe Premiere.

3. Hypothesis: “Geometry of the world is now considered to include time as well as space

Figure 12. Memory Diagram: text in conflict (painting) by Priyanki Gupta (2002).

(Eddington, 1929.)” Time based technologies (video) and generative technologies (computers) are late 20th century technologies; are these technologies applicable in time-space architectures?

Case study 7. The Memory Diagram is a symbolic, graphic negotiation of text [Fig. 11] in the painting. ‘Channels and Obliterate’ represent the conflict inherent between words and their meanings. Except for the use of a painting to represent word diagrams, the design process is the same.

Memory Design Diagrams are similar to Design Diagrams, except for the time dimension - Symbol + Message + Time = Memory. Memory Diagrams are idea oriented, layered, symbolic, schematic diagrams from which all design implementations flow. Memory Diagrams are described by the coordinates xyz + t (time); construction along a timeline allows the incorporation of sound and other time based variables. Memory Diagrams are capable of incorporating detailed modelling of animated design concepts, using both film and geometry – however, the design

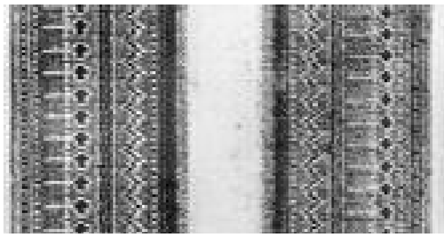


Figure 13, The Linen Girdle of Rameses III

concept is only fully realizable in memory (Flanagan, 2001).

Summary: Generative Architecture

From pre-industrial [Fig. 13] to post-industrial societies, the rationalization of process is a prerequisite in manufacturing. At present, the rationalization of design process is the predominant application of CAD in architecture – not the creation of design gestures. Two accomplished architectural design firms, Foster and Partners, London UK, and Gehry Partners, Santa Monica USA, employ design strategies founded in the rationalization and optimization of manufacturing processes. Hugh Whitehead (Foster) and James Glymph (Gehry) explain CAD in similar terms; CAD coordinates the manufacture of complex, modular architectural structures (University of Pennsylvania Symposium, Designing and Manufacturing Architecture in the Digital Age, 2002.) This at least partially debunks the myth of CAD as the designer's gesturing tool.

Form and Intelligent Function

Both benefits and limitations of CAD flow from the linear logic embedded in its digital technology. CAD's ability to optimize design and construction practice offers significant economic advantages over past practices. Case studies 1, 2 and 3 illustrate modular principles in conventional architecture that are readily adaptable to computer technology. Case study 5 illustrates an alternate approach to modular design, incorporating the advantages of traditional manufactured modules, but allowing greater design flexibility. Case studies 6 and 7 illustrate the use of time variables in the design processes; the time dimension is necessity to incorporate sound and other sensory experiences.

An emerging phenomenon in architecture is the decreasing significance of form generation in building design, a trend inversely related to an increasing reliance on information systems in building function. In today's workplace, the computer is the focus of day-to-day communication and productivity; in the automobile, the radio and cell phone entertain and inform; in the home, the television and computer increasingly dominate communication and entertainment. These new trends require the architect to negotiate imbalances in form and function, in addition to designing and constructing buildings. Architecture is likely to expand it appetite for intelligent spaces, even as the geometry of space assumes a supporting function. Precedent suggests that additional changes are in store for architecture.

Transitional Architecture

The displacement of the performance theatre by the movie theatre (in popular culture) may presage the evolution other space/information relationships in architecture. The movie theatre has distilled the architectural requirements of its predecessors into a simple unadorned box, with seats and a projection screen. The popularity of the modern movie theatre is not a simple reflection of the quality of the movie, the moviegoers spatial experience is an essential component.

The movie theatre is now an instrument of presentation; its architecture plays a supporting role to its texturing of space. If the transformation of the theatre is representative of other architectural venues, then the dimensional expansion from xyz to xyz+t (time) represents a tactical and strategic opportunity to incorporate multisensory design variables into architectural practice.

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