Chapter 1:

INTRINSICALLY LINKED THROUGH MATERIALITY: CONCEPTUAL DESIGN ~ TECHNOLOGY ~ THE ENVIRONMENT

The architectonic needs of contemporary society are being shaped by cultural issues emanating from the economy, technology and the environment. Architecture, as a manifestation of cultural preoccupations, is required to respond to these necessary issues. Education practices which have separated technical and environmental issues from the teaching and process of Design have seldom been successful in graduating Architects who are readily capable of coherently integrating these issues into Design and Practice.[1] Recent developments in the economy, the competitive employment situation for graduate Architects and the findings of the "Boyer Report" have served to highlight the importance of an integrated approach to Architectural education. The study of technology must spring from a general pedagogy that conceptual design and technology are intrinsically linked through the common factor of materiality. This manner of teaching acknowledges that structure, materiality and climatic concerns are vital determinants of form and design.

The Materiality of Modernity:

An examination of historical developments in the conceptual base of architectural design over the past 300 years reveals an intrinsic link between the development of new materials, the technological advancement of existing materials, advances in environmental control systems, and resultant architectural form and theory.[2] Little change has taken place that cannot be directly traced to the influence of new technologies. A study of the History of Architecture that does not highlight the significance of technology is incomplete; one that exploits technological issues can successfully operate as the vital link between Design (Studio) and Technology streams of study, towards an integrative and inclusive architectural education that positively influences its conceptual foundations and outcome.

It is appropriate to focus on the influence of the rapid technological advances subsequent to the early 1700's. Here we can cite the scientific divide between those structural and material inventions that were the children of "technology" versus "technique". The term 'technology' must be differentiated from that of 'technique' in order to understand its implications. Technology deals with the scientific study of a subject. Such studies have only largely come about since the onset of the Industrial Revolution with the advent of advanced mathematical, scientific and engineering studies. Through these means, science is able to be used as a testing ground for increasingly reliable predictions. Technology allowed for increased confidence in the design of accurate building structures, and an accelerated speed of documentation and construction. Technique, on the other hand, provides us with knowledge based on trial and error methodology, through information gathered via unscientific experimentation. Technology is, however, indebted to the experience of technique as an initiative for study.[3]

The design of architecture is closely linked to the materiality of the structure and system chosen to frame and clad the building, the inherent strength and performance characteristics of that material as well as climate/environmental related factors of site, sun and a Passive approach to addressing energy efficient design. Each material behaves in a unique manner -- and the technological development of architecture has been reliant on discoveries surrounding the best capabilities of each material.[4] Problems have ensued where a new material with unknown qualities has been used in a manner connected with known materials exhibiting unlike qualities. Building failures have resulted where climate appropriate response and regional building material requirements have been ignored. The materiality and environmental response of an architectural design are so intrinsically interwoven with the concept of the building, that they must be part of any initial conceptual musings regarding Design. The selection of materials should be appropriate to the nature of the intended design. One material cannot be randomly switched for another without ill effect. As well as influencing material choices, climate appropriate response directs the siting, orientation and cross sectional development of the building. The issues of regionality, environmental design, and detailing for cold, hot or humid climate performance, test the validity of certain style based conceptual design approaches.

An Architectural curriculum which highlights the intrinsic connection between structural and environmental materiality and modern architectural form and theory requires that several key topics be addressed. Environmental issues must address the basic topics of Climate type differentiation, Solar Geometry, Vernacular Architecture, Passive Heating, Passive Cooling, Thermal Performance and Sustainability. Historically, material choices were made based on regional availability.[5,6] Contemporarily, the material selection process must account for environmental considerations which not only include availability, but Sustainability.[7] The issue of structural materials ought to include from a primary viewpoint, Stone, Iron and Steel, and Reinforced Concrete. Discussion must elucidate the critical co-dependence of Structural Materiality and Processes, and Architectural Design Theory in the Industrialization of the Assemblage Building Process. The material naturally extends to include the cultural and environmental impact of technological choice.[8]

The pedagogy, presentation and evaluation must clearly demonstrate this conceptual interdependency. The format must be highly visual and make use of significant case studies, addressed in great detail. Technological issues must be simultaneously interwoven with a discussion of the impact of pertinent issues of Design and Theory that will serve to raise the level of intellectual debate and fortify the relevancy of the presentation. Such study if addressed topically rather than historically[9] can more easily trace time-line developments and design theory ramifications on a material or technique basis.[10] These time-line studies can eventually be tied together in the formulation of a complete picture. Of paramount importance is the inclusion of the "Act of Design" within the teaching format -- either with independent or Studio integrated projects (preferred).

ENVIRONMENTALLY RESPONSIVE DESIGN:

The issue of environmentally responsive design bears directly on the starting point of the design process in the way that bioclimatic considerations influence decisions surrounding the development of the site and building orientation. The incorporation of environmentally responsive issues into the teaching of the process of design requires the indoctrination of “basic principles” which will govern the thought process for all projects. These environmental or climate based issues need to be seen to spring from “Design”, rather than from “Technology”. It is the role of Design to present and make issue of the ideas. It is the role of Technology to provide supplementary information and adequate detail to allow for effective implementation of environmentally based choices.

The premise of the pedagogy of environmentally responsible design is based upon a proactive adoption of issues of Sustainability and Passive Design strategies. Sustainability and Passive Design require the cognitive inclusion of design factors arising from the bio-climatic state, the location and orientation of the site, and the use of renewable and recycled materials. Inclusion of these design factors affects the siting of the building and its cross sectional development. . In this way environmental concerns can be seen to influence the decision making process of the complete design of the building and requires integration into conceptual design process at the earliest stages of rumination.

The study of environmentally responsive design includes an examination of vernacular architecture. Prior to the advent of mechanical heating and cooling, differentiated architectural form developed that responded to local climatic factors. Passive design emulates and expands upon the successful vernacular cooling and heating strategies of climate regions whose architecture and design was not compromised during this century by the invention of mechanical heating, ventilating and cooling. Whereas Modern Architecture has been able to successfully exploit the new technologies in materials of the 19th century in terms of structural expression in building form, the International Movement in Modern Architecture has been blamed for significant losses in Passive Design and vernacular forms in both North America and Europe because of its exploitation of new heating and cooling technologies.[11] A reliance on non renewable energy intensive HVAC systems replaced climate sensitive vernacular design with buildings which ignored the implications and potential of climate due to the availability of mechanical and electrical systems and inexpensive energy. This type of design approach built an expectation of guaranteed all-season comfort, with minimal intervention by the occupant. The invention of computerized thermostats increased the passive role of the occupant. This "lifestyle", based on convenience and total comfort, has perhaps become one of the greatest barriers to the widespread adoption of both Passive and Sustainable Design principles -- contrasting the romantic and rustic attitude emulating from vernacular architecture. Such building design practices persist despite increased energy costs and environmental awareness. This attitude is promoted by Architectural curricula where stress is placed on the teaching of HVAC and artificial source lighting in technical courses estranged from the Design Studio.

Design oriented courses in the Environment, Climate or Environmental Control Systems need to occur early in the curriculum in order to allow for unencumbered incorporation into the conceptual thought process. Admittedly we cannot address everything during the first two years of the Bachelor of Architecture program. There are, however, certain essential design directing concepts that require presentation early in the curriculum and that do not require detailed technical elaboration until later in the curriculum. If presented as "Design concerns" rather than "ECS" topics, these subjects can be easily absorbed into the Design Studio or Building Technology courses and exercises.

Bioclimatic Differentiation:

The pedagogy that underlies the multitude of celebrated texts on Passive Design and Environmental Control Systems is based upon Victor Olgyay's method[12] of classifying the four primary bio-climatic regions: cold, temperate, hot-arid and hot-humid. The discussion of the History of Modern Architecture and the practice of Design can be illuminated by the presentation of significant architectural pieces whose detailed development properly responds to concerns of climate. Studies of traditional vernacular forms from which the principles of Passive design are derived are effective examples of simple/atechnical solutions to climatic conditions. These buildings may be suitably contrasted by case studies of buildings, which manage climate with fossil fuels.

The issue of human comfort is critical to the development of a design based upon correct response to bio-climatic concerns. By understanding human comfort experiences, architects can provide engaging and compelling environments, which fulfill non-visual qualities of design. This is the Natural Order of architecture[13] that is referenced by the time-tested solutions arising from technique dependent societies. The architectural notion of "The Oasis" can be used as a project basis to understand the essential connections linking climate, ultimate comfort and architectural development.

Differentiating appropriate architectural design on the basis of climate and regional concerns is essential to the education of students whose practice is increasingly international.

Solar Orientation and Shading:

The initial examination of any building site must include the routine inscribing of a "North Arrow" on the plan. The solar orientation of a building has a significant impact on the conceptual development of the building. This conceptual development will vary based on site latitude. The solar altitude angle at winter solstice will greatly affect the viability of the design solution. The orientation and cross sectional development of the building can be construed to promote solar penetration affecting an increase in daylighting levels and solar heat gain. Orientation and the proper use of shading devices are required to effect the avoidance of solar gain and glare. The design and development of shading devices alters the architectural character of the building and affects its tactile and material aspects.

The solar condition of the building affects the development of its technological requirements as well as broader issues of atmosphere, visual drama and human comfort. Solar issues are effectively taught with the use of models and heliodons, which best allow students to understand the three-dimensional and time based dynamics of the sun on architecture.

Passive Heating and Cooling Principles:

Passive heating and cooling principles derive naturally from a discussion of bioclimatic and solar design -- and form a significant aspect of the implementation of Sustainable Design practices. Passive Design, as it is incorporated within the conceptual design of a building, has major ramifications on the planning of the building, the relationship of the building to the site, and the geometry of the cross section. Many of the most successful Passive Design strategies have developed through a recognition and quantification of existing vernacular building types. These building types and architectural responses have been well documented over the past decades and follow four basic classifications: Cold, Temperate, Hot-Arid and Warm-Humid.[14, 15] Bio-climatic regionalism and vernacular practices form the basis for Passive Heating and

Cooling architectural design decisions. Passive based design strategies are incorporated into the conceptual studies for the siting, orientation, material nature, planning and cross sectional development of a building.

Sustainable Practices:

The need to introduce issues of Sustainable Design into the Architectural Curriculum is becoming vitally important. Professors of Passive Design and Environmental Control Systems have incorporated "Sustainability" into their courses as a natural extension of the principles associated with Passive and Vernacular Design. Professors of "Building and Construction Technology" are reassessing their courses in light of "Sustainable Construction Practices". Sustainability needs to be viewed as an overriding concept that influences all architectural decisions and the means by which it is incorporated into the curriculum will assist in developing an attitude that is capable of permeating all design decisions.

From a conceptual starting point, Sustainable Design practices direct the ecologically sensitive development of the site and its services, as well as the relationship of the building to the site in order to take advantage of the site while reducing environmental impact. Sustainable practices infer the use of a distinct palette of "green" materials in the detailed design of the building. The choice to use Sustainable materials greatly affects subsequent decisions regarding the structure, cladding and interior design of the building. Sustainable materials are selected which must respond to the following requirements:

- natural materials which are renewable; i.e. wood, straw
- recycled materials; i.e. plastic wood, recycled content carpet and rubber flooring, concrete aggregate
- low embodied energy materials
- regional or local materials; those that do not require excessive transportation
- low VOC materials and finishes for interiors; to promote a healthy interior

The character of buildings that make significant use of green materials creates a consequential connection between conceptual design and the materiality of the building.

STRUCTURAL MATERIALS:

Stone: Stereometry, The Rustic Hut and Gothic Revival

Stone provides an excellent starting point for discussions of the intrinsic interconnectedness of the innate technical performance qualities of a material and the resulting development of architectural expression. Exposed Stone construction has been party to a wealth of architectural stylistic expressions, substantiated by both theoretical and technological change.

By its ancient nature, revelations concerning the structural characteristics of stone are founded upon the type of experimentation that was based on techniques developed by the Greeks and Romans for their civic architecture. Even the majestic cathedrals constructed during the Gothic period relied on experimentation and often failure in the determination of the techniques which best utilized the compressive aspects of stone.[16] Such structures lacked accuracy and reliability. It was not until the 1600's and 1700's that the mathematical and scientific fields that were to have a profound effect on the architectural design of stone buildings had advanced to such a point to be of value. It was knowledge in the fields of 'mensuration' and 'stereometry' that resulted in significant technological advances in stone construction.[17] The application of stereometry to stone or other types of construction requiring accurate cutting is referred to as stereotomy, or the use of geometric projections in determining the shape and dimensions of stone or wooden elements in arches, vaults, trusses, stairs and domes. Stereometry relies on the use of horizontal and vertical projections in determining in two dimensions the precise configuration of the complex parts of a building. Such accuracy was not possible in early times, even up to the Gothic or Renaissance periods. These technological advancements owe a great deal to Humanist and Post Renaissance studies in perspective drawing and projective geometry.

A study of the Church of Ste. Genevieve by Jacques Germain Soufflot (c.1776) clearly identifies the precise technological application of stone stereometry, as well as the potentials and problems associated with the application of early principles of statics and material strengths.[18] It is important that Soufflot's architecture served as a clear theoretical statement of French Neoclassicism which took his technological applications beyond the realm of applied engineering principles.

Much speculation and theorizing regarding the historical development of stone construction transpired during the Enlightenment as archeological discoveries in Pompeii and Herculaneum unearthed ancient Greek and Roman stone buildings. Although stone construction had continued to be used throughout the ages, it was not until the Enlightenment that the field of architectural theory started to search for an understanding of its style, form and meaning. Joseph Rykwert in his book "On Adam's House in Paradise" talks at great length about the notion of 'the primitive hut', that scholars during the 1700's felt represented the origins of architectural form, from ancient buildings of timber, as translated into the stone structures of the Greeks. It was felt by scholars such as Pugin, Auguste Choisy, Marc Antoine Laugier and Quatremere de Quincy that the first buildings in history were wooden buildings, and the classical language of architecture that resulted from the design of these structures reflected the early techniques in wood joinery[19], techniques that were subsequently proved technically incorrect for the oppositional structural characteristics of stone.

The structural definition and often inappropriate use of stone material in the Rustic Hut highlights the material attributes of wood versus stone, or tension versus compression. A review of the developmental changes in stone construction can ensue, from the tensile aspects of the failed lintel, through the corbelled arch, to the Roman arch and vault, and finally to the fine tuning of compressive forces in the Gothic arch which are more correctly disposed to encourage compression.[20]

Eighteenth century thought also gave rise to speculations regarding the origins of Gothic stone structures. Sir James Hall believed that the principle of imitation was essential to architecture, and that stone as a material was problematic in that it possessed no ornamental forms proper to its nature. Hall speculated that Gothic structural language was derived from tree forms through re-enactment.[21] The discussion of Gothic language naturally extends to include nineteenth century Gothic Revival theories as expounded by Eugene Emmanual Viollet-le-Duc. An exposition of work by Antonio Gaudi, particularly the church of Sagrada Familia, provides an illuminating look at the intermarriage of aspects of Gothic structure with some innovative modern engineering principles.[22] The innate interconnectedness of structural materiality and its potentials with conceptual design is clearly visible in Gaudi's architecture. The Gothic use of exposed stone structure provided a historical point of reference and has been cited as justification for the use of exposed structure during the High Tech Movement.

Iron and Steel:

Production Iron during the late eighteenth century constituted the first truly modern structural material. The advent of Iron construction in France and England coincided with the growing separation between the definition of Architect versus Engineer[23], and gave rise to divisiveness in Architectural Theory and Education regarding the adoption and suitability for use of the material. Where formerly the material division between grand versus vernacular architecture rested between cut stone and timber or rough masonry, iron and its surrounding controversy was delegated as an industrial material. It found its best early structural uses, in overcoming its borrowed timber language, in the construction of bridges, mill buildings and arcade roofs -- which were seldom designed by Architects. Even J.N.L. Durand of the Ecole Polytechnique whose "Precis des Lecons" and its establishment of the "mecanisme de la composition" was paramount in setting forth a rationalized grid which in future allowed for the industrialization and regularization of architecture[24], rejected iron as a suitable building material.[25]

The contrasting strength attributes of Iron and Steel illustrates the archi-structural ramifications of tension versus compression -- even within a material class. The varied structural and production characteristics of cast iron, wrought iron and steel demanded differentiated architectural treatment. The mass produceability of cast iron, combined with its brittleness contrasted the crude shapes of the more elastic nature of wrought iron. Many applications can be identified which used the casting process for the production of compressive columns, combined with wrought iron trusses as tensile spanning members. The architectural detailing of the two types of members was suitably differentiated in sympathy with the necessary construction processes. The Napoleanic preference of cast versus wrought hailed not only from its capability for detailed molding[26], but also its production energy source. Whereas wrought iron used lumber to fuel its fires, a natural resource Napoleon considered in danger of depletion, cast iron required the higher heat provided by coke. (Early evidence of sustainability?)

The architectural work of Henri Labrouste, a Prix de Rome winner from the Ecole des Beaux Arts, as realized in his iron designs for the Biblioteque Ste. Genevieve (1838) and the addition to the Biblioteque Nationale (1857), raised awareness and acceptance of iron in public architecture.[27] His daring use of exposed cast and wrought iron structure, which applied amplified detailing through the exploitation of necessary connection methodology, formed the basis for a new architectural style which came to be known as Structural Rationalism. This movement supported Gothicism in creating the historical foundations for Modern High Tech Architecture.

International Industrial Exhibitions held in England and France during the latter half of the nineteenth century provided an excellent opportunity for experimentation and exploitation of iron and steel, as well as the impetus to challenge traditional methods and materials for permanent construction, with new systems suitable for fast erection and disassembly of these temporary structures. Many significant and influential architectural icons adopted iron or steel for their primary structure because of its marked strength capabilities. The Crystal Palace, designed by Joseph Paxton for the first International Industrial Exhibition of 1851, was possible only by the simultaneous rejection of traditional masonry and the appropriate adoption and applications of the principles of both cast and wrought iron construction, industrialized assembly and glass technology.[28] The high profile use of this new greenhouse architecture raised public consciousness about the new material and helped to develop a level of confidence about its structural safety in spite of the visual lightness of construction.

The large space requirements of this new type of venue provided a platform for structural experimentation which allowed for fantastical exploitations of iron and steel structural systems.[29] The Galerie des Machines by Victor Contamin and the Eiffel Tower, expressly constructed for the Paris Exposition of 1889, marked the pinnacle of nineteenth century structural steel design. The Galerie contained the largest clear space in history, with a span of 114.4 meters, achieved via application of the new three-hinged arch. The case serves as an excellent example of the ability of a hinge to rotate and thus avoid bending moment at points in the structure. The architectural expression of this specific hinge provides a clear visual reference to its connection type. The Tower brings to the table the architectural implications of the invention by Otis of the elevator, in terms of the verticality of architecture and the densification of urban settlement. Multi storey steel framing, the invention of the skyscraper, and curtain wall construction had an influence on architectural design and theory, the magnitude of which was unsurpassed. The American construction of the Brooklyn Bridge, highlighted the newfound innovative potential for pure tensile construction using steel and the accompanying clarity of architectural expression for tension. Each of the aforementioned pieces were reliant on the material and structural characteristics of iron or steel to form the basis for their existence, conceptualization, spatial configuration and architectural detailing.

In spite of the disastrous setbacks that high-rise steel construction faced due to unexpected fire damage during the early part of the twentieth century[30], the material was finally accepted and embraced by the architects of the Modern Movement. The AEG Turbine Factory by Peter Behrens (1908) and Fagus Werks by Mies Van der Rohe (1911) keynoted the material's inclusion into the language of Modern Architecture.[31] The controversial corner staircase detail of the Shoe Factory, exploiting the skeletal nature of the steel frame and the tensile ability of the material to cantilever, became an icon of Modern Style.[32] The material transcended its Industrial roots in Pierre Chareau's Glass House (1928), the iconographic continuum realized again in Mies' Glass House in Plano, Illinois.

Steel, as a structural material, became an icon for technology and modernity in the 20th century. The material of tension allowed for the creation of an architecture conceived in lightness and suspension, one requiring ballasting and mass to prevent it from taking flight. To speculate on the archi-technological ramifications of the non-existence of steel would realize the continuation of an earthbound compressive design language. It was in fact, the tensile capabilities of steel that challenged design in reinforced concrete to aspire to free itself from its inherent compressive conceptuality -- and resulted in the eventual creation of tensile reinforcement, prestressing and a structural language of pure fantasy.

Reinforced Concrete:

Reinforced concrete represents the first truly synthetic structural material, and a deeper realization of the uniqueness of strength characteristics of its components. The study of the architectural ramifications of the introduction of reinforced concrete construction, necessarily draws upon originating advances made in both stone and iron (steel) construction. The groundwork for composite material construction was prepared in the type of reinforced stone construction used in Soufflot's Ste. Genevieve, among others. This type of composite construction was significant in its exploitation of the contrasting compressive strength characteristics of stone versus the tensile capabilities of wrought iron connecting pieces.[33] In spite of the application of stereometric and engineering advancements, Ste. Genevieve would not have been possible without wrought iron reinforcement.[34]

Although the materiality of reinforced concrete did not have a significant impact on Architectural Design until the twentieth century[35], cultural and theoretical preparedness for its materialistic inclusion emanated from the Visionary Architecture of the eighteenth century.[36] The work of Etienne-Louis Boullee clearly evoked the future plasticity of reinforced concrete forms. Had Boullee lived perhaps a century later, his work was virtually realizable through the material invention of reinforced concrete shell construction. Boullee's theoretical architecture provides a referential springpoint for reinforced concrete applications in the Modern Movement by the likes of Le Corbusier. Clear precedent can be cited when comparing the use of aperture in the concrete walls of Ronchamps through likening with Boullee's Cenotaph for Newton. Boullee's Biblioteque Nationale not only recalls the spatial image of Raphael's painting "The School of Athens", but sets a precedent for the grandiose scale of imperialistic design ruminations of Third Reich Architect Albert Speer.

The intrinsic connection between Reinforced Concrete materiality and Modern Architectural Design Theory can be examined via its classifications of "Structural Typology" as well as by its unique "Stylistic" links. Four aspects of Structural Typology associated with reinforced concrete can be clearly identified. Firstly, monolithic framing, identifies the most straightforward applications of its earliest technology. Here we can cite architectural examples such as the Theatre of the Champs Elysees by Auguste Perret (1911)[37]. The Villa Savoye by LeCorbusier (1928) illustrates the adoption of the concrete structural system and its allowance for the development of his "Five Points Towards a New Architecture".[38] No other material at the time would have permitted for a free plan or roof terrace. The extension of these principles into the magnitude of application of the Unite Projects and mass housing acts as a catalyst for an urban design and cultural discussion where many cite materiality as a causal factor in the subsequent development of misdirected settlement patterns.[39]

Secondly, the excitement of plasticity and cantilevers, presents vital architectural forms which, likened to the work of Boullee, represent the reality of wild architectural vision. Without the technological developments of reinforced concrete, the work of Eero Saarinen and Pier Luigi Nervi would form an appendix to a text on Eighteenth Century French Visionary Architecture. Saarinen's use of concrete shell construction in the TWA Terminal (1956) and Dulles Airport (1958), along with many of Nervi's constructions, for example, the Palazzo del Sport (1958), highlight a type of architectural fantasy realizable only through reinforced concrete.[40] Included in this category of Structural Typology we innovative use of cantilevers, such as those found the work of Frank Lloyd Wright through the use of mushroom columns in the S.C. Johnson Building (1947)[41] and the Guggenheim Museum (1944).

The third type of Structural Typology is Long Span construction. This use of reinforced concrete includes the invention of prestressing by Eugene Freyssinnet as can be seen in his design for the Airship Hangers at Orly (1916) which enabled reinforced concrete to compete with pure tensile steel systems. Long Span construction not only influenced the course of modern architectural design, but moreover, enabled significant change in urban morphology. It provided advanced technology to support the construction of bridges (Maillart, Salginatobel Bridge (1929))[42] and general urban highway and road system networks which facilitated the decentralization of urban residential neighborhoods and industry.

The fourth category of Structural Typology refers to the industrialization of the design and construction process through the application of Precast Concrete systems. Precast concrete, as an applied modular system, has immense ramifications on modern architectural design principles. Akin to discussions about the use of mass-produced cast iron systems, precast concrete requires an examination of the impact of the desired repetition of fabricated elements and connections on both the layout and spatial qualities of the building. There are perhaps more notable unsuccessful case study applications to explore, including Moshe Safdie's design for "Habitat" at Expo 67 in Montreal, and Arthur Erikson's "Anthropology Museum" at the University of British Columbia (1975). Both projects boast unique problems peculiar to their specific structural and spatial configuration that provide an excellent basis for discussion and a workup of suggested alternate solutions, either using or avoiding precasting systems.

During the 20th century, reinforced concrete made specific material ties to the "stylistic" architectural movements of Futurism, Italian Rationalism and Brutalism. The Futurist Messagio of Antonio Sant'Elia (1914) makes a clear link between the technology of materials and the vision of a new modern architecture[43]. The North American image of the reinforced concrete grain elevator[44], an icon of industrial technology, and the fluid vision of plastic concrete forms, pervade the images of the Futurist Citta Nuova. Both monument and apartment block share the fluidity of the concrete image, a vision that can be seen to have influenced the form of housing designed under the premise of the Brutalist Movement in England.

In spite of the death of Sant'Elia and decline of Futurism, these intense images refigure in the conceptual and material base of the Italian Rationalist movement. The Italian Rationalists, under the guidance of Giuseppe Terragni (Casa del Fascio (1932)), employed the dynamic vocabulary of industrial form left to them by the Futurists[45], and with this form, a preference for the material permanence of reinforced concrete.

The materiality of concrete refigures prominently in the Brutalist Movement.[46] The roughness of board forming in the Maison Jaoul (1956) and La Tourette (1955) by LeCorbusier, as well as in work by Atelier 5 (Alder House (1958)) becomes the signature of Brutalist architecture. It is the material roughness and coldness of concrete and the associated applications of crude masonry, which when combined with urban form theories advocating high rise housing developments, eventually led to the social damning of the form with its material implications.[47] During the political upheaval at American Universities during the 1960's, Brutalist icons such as Paul Rudolph's Library were virtually destroyed.

The permanence and solidity of reinforced concrete were successful in aiding the formation of a formalist architectural typology that resulted in a close link between materiality and High Modern Architecture. Interestingly, when Modern Architecture fell into disfavor due to the pressures of Post Modernism, the material aspects of Modernism were replaced by less enduring architectural fabrics. Many unpopular edifices of the Modern Movement will endure due to their enduring materiality, well beyond the current decay of many Post Modernist constructions. Can the permanence of materiality be equated to the seriousness of intentions?

THE DESIGN IMPACT OF CONSTRUCTION PROCESSES:

The Architecture of Assembly:
The Ramifications of Industrialization on Architectural Design

The emergence of an industrialized society during the early part of the nineteenth century began to have a significant impact not only on the technology and materials which were rapidly becoming available to architects, but more importantly, industrialization necessitated a change in the way buildings were designed and planned for construction and assembly.[48] The theory of design developed and practiced by several architectural schools of the early 1800's, was successful in preparing for a changeover towards rationalized planning to facilitate modular assembly.[49] Although the economic rationale behind J.N.L. Durand's grid mecanisme de la composition at the Ecole Polytechnique was in conflict with some of the classical design principles at the Ecole des Beaux Arts[50], the shared aspects of symmetry and regularity in their planning provided a platform from which industrialized modular design in iron could easily proceed. The works of Labrouste and Paxton are testimony to the successful transfer of ideology from classical arrangement to prefabricated modular cast iron design. It is significant that the success of early industrialized applications hinged on the material qualities and limitations of iron. Needless to say, such highly organized prefabricated works would not have been possible using traditional classical materials and methods.[51]

The process of integrating the practice of industrialization into architecture and design, combined with the materiality of iron, resulted in the premise upon which the Structural Rationalist Movement was based. Structural Rationalism insisted upon the primacy of structure and the derivation of all ornamentation from innate materiality and construction processes and can be seen as an extension of aspects of Structural Classicist arguments by August Choisy who felt that the essence of architecture was construction and that all stylistic transformations were merely the logical consequence of technical development.[52] Viollet-le-Duc's Rationalist definition, diverges, however from that of Choisy and Labrouste in his disregard of the artistic questions of symmetry, in favor of truth to programmatic need, methods of construction and material properties.[53]

The essential theories that formed the basis of Structural Classicist and Structural Rationalist thought, combined with a Gothic affinity for exposed structural systems, were transported into Modern Architectural Theory as the roots for the British High Tech Movement. Reyner Banham's characterization of the "serviced shed"[54] illustrates reliance on Durand's modular grid planning, Gothic exposed structure (although now characteristically, steel), and an exposure of construction processes and detailing as the textural expression of architectural "finish". The serviced shed aesthetic recalls the structural systems and materiality of the industrial motif. Representationally, in publications, buildings such as Rogers' factory building at Inmos included exploded axonometrics of the structural assembly of the building, alongside sequence photographs illustrating the construction process. Such representation recognizes a distinct change in the perception of the architectural design and construction process, from wet to dry, from site intensive to factory controlled -- a reversal in the perceived importance of the process versus the product .[55]

The materiality of "Assemblage Architecture" draws heavily on the properties and potentials of steel "systems", making full use of the iconographic language of tensility. From the early intuitive use of tensile cross bracing in Paxton's Crystal Palace, to the purposeful lacelike appliqué on the Pompidou Centre by Piano and Rogers, the intrinsic co-conception of structural and architectural aesthetic in recognition of the material potential of structural systems peaks in the creative act of realizing "Assemblage Architecture". Of significance, as well, is the intrinsic inclusion of modularity in the two and three-dimensional spatial organization of the building. Whether an linearly extended repeated module, as in Fosters' Sainsbury Centre (1977) or the multi directional Cartesian grid extension of their Renault Factory, the notion of repetition, of both structural bay and connection detail become centrally paramount to the conceptual realization of the architectural design philosophy. There has been, in fact, a re-establishment of the craft mentality in the design and construction associated with exposed structural detailing.[56]

It is fitting that the co-dependent evolution of structural materiality and Modern architectural design should culminate in a discussion of "Assemblage Architecture". This Modern edification of the early thoughts of Structural Rationalism requires the ultimate understanding by the Architect of the potentials of materiality and structural systems in order to effect the successful detailed design of exposure. The Architecture of Assembly requires that the Architect not only have a thorough understanding of the appropriate application of structural systems and materials, but skilled hands that are capable of treating each detail with sensitivity towards its visual and constructional realization.[57] Traditional contemporary architecture, in its use of suspended ceiling systems and gypsum wall board, effectively camouflages the essential structure of the building, whose detailing may well be left to a visually unconcerned consultant, and effectively detaches the architect from the potential vitality of the Gothic reality of structure.

TOWARDS AN INTEGRATED TECHNOLOGY AND DESIGN CURRICULUM:

The process of building on a rich Architecturally Design oriented conceptual base assists the student in becoming the master of Technology rather than the servant of the engineer, through understanding the intrinsic interdependence of Conceptual Design, Structural Materiality and Environmentally Responsive Climatic Design. To effect an integrated approach to curriculum development will require that Technology and Environmental courses be represented in terms of their intrinsic link to conceptual design. This may require that technological and environmental design fundamentals be isolated from numeric justification. Fundamental issues require teaching during the first two years of the curriculum. Advanced investigation can be reserved for mature design students who are more willing and eager to increase the depth of their technical knowledge. The artificial boundaries that currently exist between the Design Studio and Technology courses must be blurred in order to permit the cross fertilization of ideas.

> “I agree with those who observed that ECS is a marginalized subject matter, but I also agree with those noting that the memorable aspects of ECS are those shown to clearly intersect with relevant matters of building construction. Perhaps, to circumvent marginalization and promote retention we need to find ways to better identify the conventional relevance of our subject so as to not concentrate on the more obscure specialization which tend to perpetuate the sense of ECS as a border concern.”
> Paul Clark. Professor of Architecture. Virginia Tech.

Even then, such an approach will achieve marginal success unless the teaching of Technology and the Environment is integrated into the Design Studio. The consensus amongst faculty who teach Technology and Environmental Control Systems concludes that effective teaching cannot take place if Technology and Environmental courses remain outside the Design Curriculum.[58] There exist architectural curricula who have made headway in effecting the integration of Technology and Environmental Control Systems into the concerns and evaluative measures of the Design Studio. Mark DeKay's, a Professor of Architecture at Washington University, recently received an ACSA New course development award for an introductory course in Environmental Control Systems wherein he employs the strategy of "ignoring" the artificial boundaries between ECS and Design by using studio projects for energy analysis.[59] Others like Lance Lavine of the University of Minnesota take a similar but opposite tactic of turning the class into a hybrid of ECS and Design Studio. This popular and more easily implemented approach is seen to have the advantage of avoiding faculty turf wars (or, at least, lessens the blood shed) and eliminates the student fear involved with illicit implementation of technological concerns in the Design Studio.

The architectonic needs of contemporary society are being shaped by cultural issues emanating from the economy, technology and the environment. If society is to be sustained, it can no longer afford Architecture that does not properly respond to technological and environmental concerns. Education practices that have separated technical and environmental issues from the teaching and process of Design must be replaced with a coherent integrated approach to Architectural Education that builds upon the intrinsic connection between conceptual design, technology and the environment.

> "The choice of technology is implicit in the choice to build. Even the use of stone corresponds to a precise technological option. It is simply that in an advanced period like our own materials are available with high levels of cohesion and durability that are easily worked and handled. It is culturally a mistake to reject the opportunity to mould an architectural language using all this potential. It is questionable even to make an issue of it. An architect, a builder, cannot help but use technological methods when it meets the design requirements."[60] Renzo Piano

The architectural examples that I have included in the paper are intended only to suggest a limited point of departure. Enrichment via the inclusion of additional significant architectural pieces, serves to expand and intensify the conceptual base to support specific archi-regional references.

Notes:

1 Black, Gary and Stephen Duff. *A Model for Teaching Structures: Finite Element Analysis in Architectural Education.* JAE September 1994. Referencing an ACSA Memo of 1976 regarding dissatisfaction with the teaching of Structures in Architectural Schools.
"...structures cannot exist as a completely separate discipline but must be approached in a manner which is always oriented toward the total design process. ...The classical sequence of presenting physics, statics, strength of materials, analysis and "design" may represent a logical progression of information. However, divorced as it usually is from involvement with the total process of design, this sequence has resulted in architectural graduates who have no understanding of the basic principles involved, cannot apply them..."

2 Mainstone, Rowland. *Developments in Structural Form.* MIT Press, 1983. p.20

3 Wilson, Forrest. *The Joy of Building.* Van Nostrand Reinhold, 1979. p.43

4 Tzonis Alexander and Liane Lefaivre. *The Mechanization of Architecture and the Birth of Functionalism.* VIA 7. Architectural Journal of the Graduate School of Fine Arts. University of Pennsylvania. p.130-131
...extending initial observations by Galileo... "Thus gradually the complete building fabric was seen in analogy with the machine. Its form did not follow the Idea; instead it was determined by the behavior of the matter. The shape of its components depended on their material, their composition, and their size."

[5] Mainstone, Rowland. *Developments in Structural Form.* MIT Press, 1983. p.53. A natural form of cement originated in Pozzuoli, Italy, making concrete a viable material for the Romans in buildings such as the Coliseum. Transportation of the material was prohibitive. It was not until the 1700's that Portland Cement was invented, making concrete construction possible on a widespread basis in England.

[6] Condit, Carl. *American Building.* University of Chicago Press, 1982. p.168-169. Development in North America did not occur on a widespread basis until the later 1800's due to material availability.

[7] Cole, Ray. SBSE Summer Retreat 1994. *Buildings and the Environment: Emerging Research Questions and Directions.* 2.0 Environmental Analysis of Materials.

[8] Bachman, Leonard, Mary Guzowski and Robert Pena. *Toward an Ethic of Elegance: Discovering Environmental Principles in Early Design Studios.* ACSA Technology Conference.

"While a more quantitative study of energy and environmental controls may be most appropriately addressed during advanced levels of architectural study, we feel it is vitally important that an appreciation and conceptual understanding of sun, light, wind and sound be developed during the formative studio settings." ECS instructors cite similar concerns regarding the lack of an integrative approach to introducing ECS concepts into the design curriculum. It is my intention that the intrinsic link between environmental concerns and conceptual design be simultaneously established within the formative curriculum proposed.

[9] Pevsner, Nikolaus. *A History of Building Types.* Princeton University Press, 1976. p.289-290

Only in his conclusion does the author identify a tracing of the materiality of structure as an interconnected narrative with a change or evolution in building typology.

[10] Mainstone, Rowland. *Developments in Structural Form.* MIT Press, 1983. Although I frequently cite this text as a reference during my Structural Material lectures, the organization of its content in terms of structural systems and member types makes it difficult to trace the stylistic and theoretical ramifications on the development of modern architecture.

[11] Moore, Fuller. *Environmental Control Systems.* New York: McGraw-Hill, Inc., 1993. p.4

[12] Olgyay, Victor. *Design With Climate: A Bioclimatic Approach to Architectural Regionalism.* New York: Van Nostrand Reinhold, 1963, 1992.

[13] Bachman, Leonard. College of Architecture. University of Houston. *Course Notes for Environmental Control Systems.* 1995.

[14] Olgyay, Victor. *Design With Climate: A Bioclimatic Approach to Architectural Regionalism.* New York: Van Nostrand Reinhold, 1963, 1992.

[15] Moore, Fuller. *Environmental Control Systems.* New York: McGraw-Hill, Inc., 1993. p.41-54.

[16] Acland, James. *The Gothic Vault.* University of Toronto Press, 1972. p.110 ...a discussion of the structural problems and innovations following the collapse in 1284 of the choir vaults of the Cathedral of Beauvais, France.

[17] Perez-Gomez, Alberto. *Architecture and the Crisis of Modern Science.* MIT Press, 1984. p.227-235.

"The geometry implicit in vault construction and other stereotomic marvels, constituted, like the mathematical order of a fugue, both the structure of the work and the ultimate source of its meaning. ... Desargues was conscious of the fact that no one before him had reduced the art of stonecutting to a set of methodical and universal principles."

18 Perez-Gomez, Alberto. *Architecture and the Crisis of Modern Science.* p. 68-69.

"The crucial reconciliation between aesthetic and technical interests ... is particularly evident in the work of Jacques Germain Soufflot, whose most significant creation, the church of Ste. Genevieve, represents the culmination of French Neoclassicism, embodying that taste that admired the lightness of Gothic structures and the purity and grace of Greek architecture. In this building, it is impossible to establish where aesthetic motivations end or at what point design decisions were prompted by an intention to rationalize the structural system. ... His scientific observations were instrumental in determining the proportions of Ste. Genevieve, particularly the dimensions of the structurally critical central piers under the dome."

19 Rykwert, Joseph. *On Adam's House in Paradise.* p.35.

quoting Pugin. ""...the architects of the middle ages were the first who turned the properties of materials to their full account, and made their mechanism a feature of their art." He turns to Greek architecture for a confirmation of his argument. "Grecian architecture," he argues, following the ancient authorities, "is essentially wooden in its construction ... never did its professors possess either sufficient imagination or skill to conceive any departure from the original type ... [it] is at once the most ancient and barbarous mode of building that can be imagined; it is heavy ... and essentially wooden; but it is extraordinary that when the Greeks commenced building in stone the properties of this material did not suggest to them some different and improved mode of construction. Such, however, was not the case; they laid stone lintels, as they had laid wooden ones, flat across. ... The finest temple of the Greeks is constructed on the same principle as a large wooden cabin.""

20 Wilson, Forrest. *Structure: The Essence of Architecture.* A wonderfully illustrated sequence of examples of the action of forces in arched and vaulted shapes, deformation and failure modes.

21 Rykwert, Joseph. *On Adam's House in Paradise.* p.82-85

"A row of equidistant poles of more or less the same height is fixed in the ground, as in various accounts of the origins of the orders. But to each of these "Gothic" poles, a surround of pliant willow rods is applied and fixed. When the opposite willow rods are brought together and tied, the resulting form is something like a groined vault ... Small variations in the joining of the willow rods provide the models for varieties of arching and vaulting. ...so the pointed arch, the clustered column, the branching roof, "the three leading characteristics of Gothic architecture," have been accounted for."

22 Salvadori, Mario. *Structure in Architecture.* Prentice-Hall, 1986. p.132. Regarding Gaudi's adaptation of the Funicular Arch in the Church of Sagrada Familia, Barcelona.

23 Middleton, Robin. *The Beaux Arts.* MIT Press, 1982. p.19

24 Perez-Gomez. *Architecture and the Crisis of Modern Science.* p.304

25 Durand, J.N.L. *Lecons D'Architecture. Partie Graphique des Cours D'Architecture.*

26 Steiner, Frances H. *French Iron Architecture.* UMI Research Press, 1984. p.28

27 Middleton, Robin. *The Beaux Arts.* MIT Press, 1982. p.155

28 Kihlstedt, Folke. *The Crystal Palace.* Scientific American. October 1984. p.132-143

29 Benevolo, Leonardo. *History of Modern Architecture.* MIT Press, 1984. p.105-120

30 Benevolo, Leonardo. *History of Modern Architecture.* MIT Press, 1984. p.117-118

"Iron buildings now seemed to have reached the limit of their possibilities. ... During the last decades of the century rapid progress was made, on the other hand, in the new means of building, reinforced concrete, which soon became very important in ordinary building because it was so economical, particularly after the publication of the building codes."

Insufficient resistance to Fire damage for reasons of structural integrity and personal safety continues to impede the widespread use of steel in many types of construction. Invention of a paint like intumescent coating during the past 10 years has been able to increase the fire resistance rating of steel from 3/4 hour to 1 hour, which has enabled its exposed use in a greater number of occupancy classifications. Early failures due collapse during fire over loss of strength were not anticipated as steel had originally replaced timber in mill construction because of its decreased flammability.

31 Banham, Reyner. *Theory and Design in the First Machine Age.* MIT Press, 1983. p.84

"Curiously, these more enterprising designs of Behrens left less mark on subsequent architectural thought and feeling than did the Turbinenfabrik, which seems to have served as a model even for post-War Expressionist architecture. ... Here Behrens is most closely to be compared with Auguste Perret, the latter having brought a new material -- concrete -- within the accepted canons of architectural thought."

32 Banham, Reyner. *Theory and Design in the First Machine Age.* MIT Press, 1983. p.79

"...but these glazed blocks, with their windows rising continuously through three stories, and wrapped around the corners of the block without corner piers, stand out as major innovations..."

33 Mainstone, Rowland. *Developments in Structural Form.* MIT Press, 1983. p.60

34 Benevolo, Leonardo. *History of Modern Architecture.* MIT Press, 1984. p.12

"...the real stability of the cornice was ensured by a close network of metal bars, arranged rationally according to the various stresses, like the skeleton of a modern work in concrete."

35 Pevsner, Nikolaus. *A History of Building Types.* Princeton University Press, 1976. p.290

36 Perez-Gomez, Alberto. *Architecture and the Crisis of Modern Science.* MIT Press, 1983. p.134-146

37 Benevolo, Leonardo. *History of Modern Architecture.* MIT Press, 1984. p.326

"A structure in reinforced concrete of the type used by Perret consists of a skeleton of pillars and girders on which the horizontal structures, the external non load-bearing walls and any internal divisions are supported.

38 Benevolo, Leonardo. *History of Modern Architecture.* MIT Press, 1984. p.444-445

39 Scully, Vincent. *American Architecture and Urbanism.* Henry Holt and Company, 1988. p.165-166

"The concept of the superblock ... was eventually to be employed with catastrophic visual and social results in the redevelopment projects of the 1950's and 1960's. Jane Jacobs pointed out ... in her admirable "The Life and Death of American Cities" of 1961. ...at a large urban scale it had another ancestor also -- LeCorbusier himself."

40 Mainstone, Rowland. *Developments in Structural Form.* MIT Press, 1983. p.226-228

41 Curtis, William. *Modern Architecture Since 1900.* Prentice-Hall Inc., 1982. 200-202

"...you are now released by way of glass and the cantilever and the sense of space which becomes operative. ...The architect had to prove to his nervous clients that his slender columns could support the anticipated loads by building a mock-up and piling heavy weights on it. This experiment only went to confirm the integration of Wright's practical engineering knowledge with his intuitive structural sense."

42 Wodehouse, Lawrence and Marian Moffett. *A History of Western Architecture.* Mayfield Publishing Company, 1989. p.439

"By 1900 Hennebique alone had designed and built more than 3,000 structures of plain or reinforced concrete, including over 100 bridges. ... Maillart is perhaps more famous for his reinforced concrete bridges, which combined the arch of the structure with the horizontal surface of the roadway in a single unitary design."

43 Frampton, Kenneth. *Modern Architecture: A Critical History.* p87.

"Calculations of the resistance of materials, the use of reinforced concrete and iron exclude 'Architecture' as understood in the Classical or traditional sense. Modern structural materials and our scientific concepts absolutely do not lend themselves to the disciplines of historical styles ...We must invent and rebuild ex novo our modern city ... but the stairs - now useless - must be abolished, and the lifts must swarm up the facades like serpents of glass and iron. The house of cement, iron and glass, without carved or painted ornament, rich only in the inherent beauty of its lines and modeling..."

44 LeCorbusier. *Vers Une Architecture.* 1923 Cover photo of a grain elevator.

The grain elevator has of recent years been the iconographic target for salvation by historical societies in Toronto and Montreal, as the majority of mills have been slated for demolition by local Planning Authorities. It has been recognized as a significant piece of industrial architecture, representative of early modern architecture of this century.

45 *From Futurism to Rationalism.* Architectural Design 51, 1981. p.72-79

46 Frampton, Kenneth. *Modern Architecture: A Critical History.* Oxford University Press, 1980. p.265

"Up to the mid-1950's truth to materials remained an essential precept of Brutalist architecture..."

47 Wodehouse, Lawrence and Marian Moffett. *History of Western Architecture.* Mayfield Publishing Company, 1989. p.478-480

"The concrete work throughout is forceful. ... LeCorbusier's critics have pointed out that the scheme is essentially antiurban, turning its back on the architectural and street patterns of Marseilles."

48 Tzonis Alexander and Liane Lefaivre. *The Mechanization of Architecture and the Birth of Functionalism.* VIA 7. Architectural Journal of the Graduate School of Fine Arts. University of Pennsylvania. p.121

49 Madrazo, Leandro. *Durand and the Science of Architecture.* JAE. September 1994. p12-13

"By the end of the eighteenth century there was a growing concern that architecture was falling behind the new sciences in terms of progress. As a result, attempts began to be made to construct a science of architecture. The work of Jean-Nicolas-Louis Durand epitomizes this effort to achieve a systematization of architectural knowledge."

50 Madrazo, Leandro. *Durand and the Science of Architecture.* JAE. September 1994. p.16

"At first sight, it looks as if the purpose of the method is to produce a neoclassical building in a logical way. This is not the case, however, because the goal that Durand is pursuing with his method is independent of stylistic considerations."

51 Kihlstedt, Folke. *The Crystal Palace.* Scientific American. October 1984. p.132

"As with these earlier constructions (Pantheon, Hagia Sophia, St. Denis) the extraordinary functional demands made on the Crystal Palace stimulated a design that refined and extended the structural practices of the time, resulting in an architecture novel in its form and aesthetic."

52 Frampton, Kenneth. *Modern Architecture: A Critical History.* p.19.

53 Frampton, Kenneth. *Modern Architecture: A Critical History.* p.64.

54 Lyall, Sutherland. *The State of British Architecture.* p.113.

55 Extensive discussions during the 1980's with Ron Keenberg of IKOY and Forrest Wilson regarding the creation of a matrix for architectural design and its assembly.
56 Dini, Massimo. *Renzo Piano: Projects and Buildings 1964-1983.* Rizzoli, 1983. p.7
57 Glancy, Jonathan. *Piano Pieces. The Architectural Review.* May 1985. p.59
"Mention new materials to Renzo Piano and you are just as likely to be treated to a discussion on coconut fibre, mud and iron as you are to one on the new generation super-strength polycarbonates. Piano is concerned with what is appropriate. Although an inventive and encyclopaedic source of information on new building materials, Renzo Piano is not a slave to them."
58 Rand, Patrick and Hunt McKinnon. Connector.
59 DeKay, Mark. Proceedings of the th Annual Passive Design Conference. April 1996.
60 Dini, Massimo. *Renzo Piano: Projects and Buildings 1964-1983.* Rizzoli, 1983. p.7