Appendix
A. Appendix

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A1: Relevance of Architectural Research

This discussion of architectural research is meant to provide practicing professionals, academicians, and students in architecture and the related design fields with a reference to rapidly emerging field of architectural research. Architectural research is systematic inquiry directed toward the creation and development of knowledge—so that it can be used to understand or change in a positive manner the production of architecture. This inquiry may be in the field of form of knowledge development in order to solve a problem (applied research) or in the form of knowledge (basic research).

Frequently, there are two methods of inquiry generally used oftenly having conflicting views. Inquiry follows a path of hypothesizing or intuitive understanding, deduction or reasoning, experimentation and inference or concluding. Beliefs or theories are tested, substantiated and added to the body of knowledge. An accepted set of rules must govern the process; acceptability depends on a rigorous methodology of inquiry and the ability to validate the findings or conclusions. In other words, intuition and inspiration can generate the relationships—that must then be tested objectively.

A1.1 Need for Architectural Research

The desire to understand is a fundamental attribute of humanity. Obviously the architectural profession desires to understand to have knowledge. However, the process of gaining knowledge in the architectural profession through architectural research is more a question of the responsibility of various parties to create, as well as to apply this knowledge.

There is a growing awareness among the building industry and the public that the built environment too often fails—in aesthetic, functional, social, and economic performance—and that the industry has not developed socially or technologically like other industries and components of society. In the past, the body of knowledge grew at a pace that could be internalised by solid vocational training and professional experience. The fundamental covered in universities spanned most of the professional’s life. However, the increasing pace of post industrial technological change has exploded the knowledge base. Traditional forms of profession and institutional information and knowledge transfer can no longer cope with these rapid advancements. The world in which the architectural profession designs is simply too complex; this requires more and better knowledge more rapidly developed and transferred to the architectural profession.
This creation of knowledge must become an integral part of the architectural profession. Architects must be educated to become a professional for both knowledge creators and knowledge appliers. This is the model for most professions and universities. However, neither the building industry, nor the architectural profession, and the schools of architecture are structured in this way—that facilitates or promotes systematic inquiry for the purpose of building knowledge.

Knowledge is presently built within firms through a progression of architectural commissions and reliance on technical consultants. There is little systematic contribution to, or reliance on, for a larger knowledge base.

The intellectual tradition or architectural education emphasizes precedent and adaptation rather than actual knowledge development. Only a handful of schools of architecture have moved away from this tradition of professional design education toward the more prevalent university mode of knowledge development.

The present nature of architectural research, including the methods employed in the research and the results derived from the research and applied to the profession, comes primarily from four areas namely the humanities, the natural sciences, the social sciences, and the management sciences.

Mathematics (the humanities category) has most recently begun to play an increasingly very important role in the acquisition of new knowledge in the area of architectural computer-application.

Since the emergence of the engineering professions, the natural sciences have become strong allies in the development of architectural knowledge, also. The natural laws of physics (statics, dynamics, and thermodynamics) that dictate the behaviour of the building physically, have been applied directly into the profession within the structural, material, energy, and lighting aspects of building design.

The systematic study of economic to understand the consequences of the applications of new knowledge and technologies—is playing a larger and larger role in architectural research.

The management sciences are playing an active role in the areas development important to architectural profession in the dynamic programming, besides others.

In united states (USA), hundreds of architectural research projects performed by hundreds of researchers, worth millions of dollars is now the norm. Although small in comparison to the other professions, it is nonetheless a beginning. It is hoped that within next 10 years, will see it growing into a recognized and integral part of the profession of architecture.
In brief all of these fields and disciplines have been instrumental in the formulation of architectural inquiry and the development of knowledge that is used daily in the practice of architecture and in the education of architects.

With any transfer of information from separate disciplines to a new field there is a transformation that occurs with the integration of this knowledge. Within architectural research, this transformation has been the emergence of new methods of research and new ways to present the findings for more responsive applications in the profession.

A1.2 Methods of Architectural Research

Applied architectural research is undertaken to produce knowledge to promote informed action. This knowledge has clear uses within the programming, designing, building, operating, and evaluating processes. Architectural research not linked specifically to stages in their process runs the risk of being irrelevant in the eyes of the practitioner and educator.

The process of architectural research to fulfil this need usually consists of five distinct phases: measurement of performance, prediction of performance, generation of alternative solutions, selection of alternative solutions, and measurement of performance achieved.

This process attempts to follow the path of scientific inquiry. The measurement of performance consists of either using the data to generate hypotheses or hypothesizing first and measuring the data to substantiate the hypothesis, the prediction of performance based on reasoning and deduction applied to the measured data, the generation of alternative solutions to provide the basis for an experiment or for comparisons of potential solutions to particular problems identified by the data, the final selection of alternative solutions that correspond to the findings and conclusions of the research, and the eventual evaluation and measurement of the performance attained by these solutions in order to sustain, modify or refute the hypotheses.

Architectural research on the process of design typically looks to the entire process of the delivery of design in order to understand the relationships—so that better technologies and management techniques can be brought to bear on the design of the built environment.

Architectural research into building technology examines the performance and use of various building technologies (systems, components, materials, equipment) in order to recommend or develop more appropriate technologies to fulfil design requirements.
However, there is a real need to demonstrate the breadth of architectural research, the large number of severe problems that wait to be solved, and the large amounts of knowledge that wait to be found.

A1.3 Conclusions

Most fields of professional practice have evolved during the course of the twentieth century from total reliance on intuitive understanding, experience, and historical precedent to a significant emphasis on research and scholarship as a basis for practice. This progression can clearly be seen in the profession of law, medicine, and engineering. Such changes have had profound impacts on their training and practice.

This evolution seems to have progressed much more slowly in the field of architecture. The call for such an expanded and depended knowledge base has received only limited support from most of the profession. But there are signs that a tradition of research within architecture is slowly beginning to evolve.

Architecture cannot be based entirely on intuition, experience, and precedent. It must also be based on knowledge carefully acquired through research. The belief is not that such knowledge can inform and improve both the design process and the final architecture.

A2: Structure Systems and Related Architectural Design
Development Aspects: Discussion

A2.1 Introduction

Architecture has many expressions. One may define it as an attempt to control the physical environment, while providing for the needs of various plan-shapes in the form of: houses, schools, hospitals, synagogues, churches, offices, shopping centres, theatres, factories, etc. These practical expressions of architecture stand out as semi-permanent reminders of success-or failure. The thought processes, the search for client needs, the logic employed, the complex interrelationships of spaces involved, the programming, the simulation— and the evaluation of various designs, all these— so vitally important to the final design— remain hidden in the architect's office. What is evident for all to see is a physical structure, built from concrete or steel or timber, clad in brick or stone or glass, roofed/floored as appropriate— that withstands such natural elements such as snow, wind and rain, and provides an enclosed or unenclosed space for the client. The architect, with the help of the structural engineer, and the builder, has converted ideas related to form, shape, and space— into a building. Whereas all the ideas subtly expressed are half-hidden, the structure and the materials of construction may be quite exposed and totally visible for all to use and see. Therefore structure has become a vital— and perhaps the most exposed part in architecture. The interface between architecture and structure is a fascinating field, and one— that needs to be explored more deeply. Structure should influence architecture by making it more rational and efficient, but it should not dictate architecture.

A2.2 Importance of Structure Systems to Architects

The importance of a knowledge of structure systems to architects is now becoming quite obvious. Architects need this knowledge to ensure that the practical expressions of their architecture are both rational and efficient. The structural system that enables building to withstand the loads imposed on them, and the materials of construction, if properly chosen, can help in furthering the expression of architects' ideas rationally. If improperly chosen, structure systems and materials of construction may work against an architect.

Some might argue that, because architects always work with consulting structural engineers, who make the final decisions on the structural systems, and the size(s) to be used, a knowledge of structures is not really necessary for architects. There are two major objections to this argument. First, the architect who knows no structure hands over his beautiful piece of architecture to an engineer, possibly an unthinking, and unfeeling one, who then inserts a structural system into it. The engineer's decisions follow his own philosophy and training, including such factors as ease of calculation or construction, and it may express something quite different
from the architect's overall philosophy. The second and greater objection is that an architect ignorant of structures may propose a piece of architecture— that cannot be built at the price, the client is prepared to pay. In other words, this architecture is a pipe-dream, a futile intellectual exercise— far from the realm of reality.

Conversely, the architect who has an adequate background in structures will have relied on that background, even if sub-consciously, from the initial stages and will produce a feasible and practical design. Furthermore, in his consultations with the structural engineer, he will be able to discuss his objectives intelligently, and to resist suggested changes. And, architect operates from position of knowledge, and strength.

A2.3 Structural Systems and Architectural Design

It is now clear that an architectural design must incorporate a structural system or systems that will help the architect transform, conveniently and safely the design into a structure— that rests the elements, and encloses spaces according to his original ideas. Thus it is the initial architectural design, that provides the architect with the first data, that will enable him to make rational choices. What are the spans involved? What are the shapes and size of the spaces? Is unobstructed space wanted or column supports— that puncture the space at regular intervals? Structural systems suitable for spans of 30 ft (9.14m), may be quite unsuitable for spans of 100 ft (30.48 m), and vice versa. Architects must realize that, although the architectural design has spans or spaces of its own, the spans they impose on the structural systems, influence the choice of that very system. And spans are not the only data, that can be learned from the architectural design.

Equally important is the realization that the architectural design, by its shape in plan and elevation and by the objectives it tries to achieve, can suggest other structural systems better suited to the design itself.

A2.4 Structure Systems and Loads

The structural system, now an essential part of the architectural design, and suitable for the spans involved, forms and supports the enclosed spaces— that are to meet the architect's objectives, and fulfil the needs of the client. The structure then will be subjected to loads, from both inside and outside the building. Loads from inside the building are imposed by the occupancy or the use to which the building is put, and may consist of live loads due to people, furniture, library-books racks, automobiles, hospital beds, etc. or any combination of these as appropriate. Other loads inside the building arise from the dead load of the total construction itself. The structure system must be capable of taking its own load, and also the loads imposed on it by flooring, permanent internal partitions, external cladding walls, ceilings, roofing, such mechanical systems as ducts, etc.
Loads from outside stem from the effects of the natural environment on
the building. These may consist of snow load on the roof, and sides, and perhaps
earthquake loads. These loads depend largely on the location of the building.

All these loads, whether from inside or outside the building, whether
arising from the building itself, the user, or the natural elements, have to be taken by
the structural system from all points, and manners of application and then
transferred safely to the foundations, where they are then dissipated into the soil on
which the building rests. This is the function of structure in architecture, and its
importance can hardly be underestimated, in the modern needs of technological
means.

A2.5 Structure Systems and Building Materials

Having considered the structural system, the architect then chooses the
materials of construction. Sometimes the choice is dictated by experience, which
suggests that certain structural systems are compatible only with certain materials of
construction. For instance, timber is totally unsuitable and incompatible as the main
structural material in a high-rise building. Such a building requires a structural
system in steel or concrete. The incompatibility of the material of construction with
the structural system chosen, may be governed in some cases by the consideration,
that final sizes would be either too large or too small to warrant an rational structure.
For instance, steel is extremely strong in tension, but concrete is not. Steel is also, for
the strength it affords, is a comparatively light structural material, whereas concrete
is heavy. The dead load of a steel structure, is therefore quite small, and the dead
load of a concrete structure is quite large. A light, large-span, cable-net roof
structure, which uses tension as the primary means of load propagation, to transfer
the loads from the roof toward the supports, is therefore very suitable in steel, but
unsuitable in concrete.

The nature of the material, is not the only alone reason for incompatibility
between the structural system and material of its construction. Various other degrees
of incompatibility can arise from a number of reasons, such as the architect’s esthetic
requirements; building code requirements; particularly the fire codes; ready or poor
availability of material: local methods and practices; and finally economics!

A2.6 Structure Systems: Design Development Logic

After, having weighed structural systems and compatible building
materials, the architect is in a position to design his structure. He uses a structural
system he wishes to use. He has also estimated the loads that will be imposed on it,
for the chosen material of construction. He cannot be fully sure that his choices have
been rational, however, until he is able to approximately size the members of his
structural system to determine whether or not the entire system is going to be
feasible. Should he try another structural material, such as steel? Should he try
perhaps another structural arrangement in the same type of structural system, to reduce his structural depth? Should he adopt an entirely different structural system altogether? Should he alter his spans, and perhaps compromise his architectural design? These are fundamental questions, the architect cannot conceivably, even, begin to answer, until he is able to approximately size his members for construction purposes, perhaps by using more sophisticated methods of analysis. The architect, however, needs an approximate size, not to duplicate the efforts of, but, enabling him to improve his architectural design-development-patterns.

For studying the structural behavior adequately, the architect needs to fully appreciate two separate stages of design.

(1) He needs to know how load propagates or flows through the various elements of his structure. This is analysis.

(2) He needs to know how this propagation, or flow of load affects the material of his structural element, so that he can provide an adequate amount of material for the structural element to be safe. This is sizing of members and more properly may be termed: Design Development.

Each stage is discussed as follows:

A2.6.1 Load Propagation Through the Structural Systems: Load Propagation

Fundamentally, structural system collects the loads from the points of application - snow load on the roof, wind load on the roof and sides, live or user loads on the floors, dead load everywhere, etc.— and transmits them to the foundations. The load in fact propagates, or flows, from the point of application, with the help of structural mechanism of load transfer, along and through the structural system to the foundations. The particular mechanism or combination of mechanisms used, is vitally important for a proper understanding of the behavior of the structural system and, hence, to design properly for the structure system.

And also, it is vital to discuss and to determine the correct path of load propagation, and manner in which transfer and flow of load occurs, is critical to an appreciation of the behavior of the structural system and, hence, to its analysis and design.

A2.6.2 Load Propagation: Design Consideration

The load, in its path through the structural system, stresses and strains the material in various ways. An understanding of how this occurs is essential to a proper understanding of the structure. It needs to have a sufficiently large area of cross section, therefore, so that it does not snap. To phrase it differently, the tensile stress in the material of the member must be below the ultimate tensile of the material with certain factor of safety of 1.4 to 1.5, due to defective workmanship, and our ignorance of extra-loading and defective connections, which may lead to
overstressing locally. The factor of safety is really our factor of ignorance, which we apply to ensure that the structure is safe at all times, and under all conditions.

There are generally two ways of applying factor of safety in structural design. In working stress design, this factor of safety is applied to the ultimate strength of the material to yield a permissible stress, up to which the material can safely be stressed for the load on the structure: working load, structure normally takes under all conditions of working operations in life cycles.

In ultimate load or strength design, however, the factor of safety is applied to the working load to yield a much larger load, for purpose of design, called the ultimate load.

This ultimate load is a factious value, because it is never expected to be reached. The structure is then designed in such a way that the ultimate strength of the material would in fact be reached under the ultimate load — and collapse would occur.

In brief, Strength is not the only criterion of design alone; Deflections encountered while loading, are equally important for design development considerations.

A2.7 Conclusions

The architect can now choose his structural system, and his materials of construction. He has to account for load propagation through his structural system, and the effects of that propagation on the material. Thus he can provide enough material through members of proper sizes — for all elements of his structure, to ensure that the internal stresses developed are less those permissible for the material in question. He can also ensure that deflections, his structural members will undergo as a result of loading-strain are also less than those permissible for the member. He has in fact sized his members safely adequately sufficient. And in so doing, he has configured his structure systems logically: for Architectural Design Development.

A3: Glossary of Technical and Associated Terms

Glossary of selected technical and associated terms used in present thesis work are appended to facilitate comprehension of the text and further clarification.

**ACTION or (ACTIVE LOAD)**: Load or set of loads acting on a structure or structural element— that it is decided to regard as the primary one. Commonly, dead load plus imposed loads, that the structure or element is designed to carry— as distinct from the counterbalancing set of loads, exerted by the supports or adjacent elements.

**ARCH**: A structural element capable of spanning a horizontal gap and carrying its own weight and other loads wholly or largely by internal compression. Usually it is curved in profile.

**BEAM**: A structural element capable, like an arch or catenary, for spanning horizontal gap, but acting structurally as a combination of the two. Usually of straight horizontal profile, though it may vary in depth according to the expected variations in bending moment.

**BEARING WALL**: A wall of that fulfils a primary structural role as a vertical support for loads other than its self-weight.

**BENDING**: A type of deformation in which initially-parallel cross-section of a structural element become inclined towards one another; and the type of structural action that leads to this deformation.

**BENDING MOMENT**: An external moment leading to the bending of a structural element, and the couple at any cross-section due to the internal tensions and compressions that are called into play to resist the external moment.

**BUCKLE**: To bend suddenly out of the original line or surface under the action of a slowly increasing primary compression, that is not perfectly axial; or, more generally, to suffer a rapid loss of stiffness in relation to this compression, owing to increases in the secondary bending moments due to its non-axiality.

**CANTILEVER**: A beam or slab supported at one end or edge only, projecting out from it, and restrained from rotating about it.
CATENARY

Strictly, the curve assumed by a chain or cable uniformly loaded along its length and freely suspended from two horizontally-separated points. Used here though in the sense of catena to denote the hanging chain or cable itself as a structural element capable, (as the counter-part of the arch) of spanning a horizontal gap and carrying its own weight and other loads wholly by internal tension.

CENTERING

The temporary supports on which an arch or vault is frequently constructed or on which the formwork for it is carried.

It is usually of timber or steel. It may itself be propped up directly from the ground.

COMPONENT (of structural action)

That lesser action that would be equivalent to it in another direction or another plane, but would act solely in that other direction or plane.

COMPRESSION

Contraction and the type of structural action that leads directly to it.

CONTINUOUS

Of a structural element such as a beam, column or slab with more than the minimum number of supports or attachments to keep it in place, capable of transmitting bending moments from one side of an intermediate support or attachment to the other. Such moments are thereby shared by all spans or lengths and the structural action is made statically indeterminate by the continuities or from another point of view, by the additional supports or attachments.

DAMPING

Dissipation of the energy of disturbing forces, particularly periodic ones, by turning it into a form of energy that is not associated with structural deformation or displacement.

DEAD LOAD

Self-weight plus the weight of other permanent construction carried by the structural element of structure under consideration.

DEFORMATION

Change in shape or dimensions as a result of or as part of a structural action.

DENSITY

The mass of a unit volume of a material. More commonly, the weight of a unit volume.
DIAPHAGM: A transverse plate or similar member in a box beam, box girder, or column of similar form introduced for the purpose of stiffening the sides where these are in compression and, more generally, of maintaining the shape of the cross-section and the uniformity of the internal distribution of loads and stresses.

DUCTILE (DUCTILITY): Capable of carrying loads at or near the ultimate strength over a wide range of deformation rather than failing in a brittle manner.

DYNAMIC LOAD: A load that is applied or changes sufficiently rapidly to bring into play significant inertial resistances and thus frequently to have an effect markedly different from that of an otherwise identical load applied more slowly and acting more continuously.

ELASTIC (ELASTICITY): Capable of returning to the original shape and dimensions when a load is removed. A property well exemplified by a spring provided that it is not overloaded.

ELASTIC DEFORMATION: That part of the total deformation under load that disappears when the load is removed.

ELEMENT (STRUCTURAL ELEMENT): A basic unit of construction self-sufficiently capable of carrying its self-weight and other loads to its supports. Arch, beam, catenary, column, dome, false arch, folded plate, membrane, shear wall, shell, slab, strut, tie, vault, wall. Frames, grids, and trusses are designed to act in analogous ways.

EQUILIBRIUM: A state of balance of all the loads acting on a structure or any part of it. It will be Static if no dynamic or inertial loads are involved, and will then be a state of rest. Otherwise it is Dynamic, and will entail continually changing deformations and displacements. When unqualified it should usually be read as denoting the static state. It may also be either be stable or unstable.

FORCE: A linear structural action (usually in practice, the notional concentrated equivalent of a more dispersed one) — that tends to initiate motion in or change the state of motion of any body on which it acts, or that results directly from an imposed change in the state of rest or motion of the body.
FOUNDATION: That part of a structure that meets the ground and through which all loads are transferred to it.

FUNCTIONALISM: An architectural philosophy emphasizing the uses (function) of a building and its parts and revealing its structure and materials. Functionalism emerged in the twentieth century and was a major principle of the International style.

FUTURISM: Primarily a fine arts style, Futurism was a major movement in the 1910s in Italy and displays in its architecture an enthusiasm for modern technology and industry.

GRID: An open structural form acting in a manner broadly analogous to that of a slab (discretised), but consisting of interconnected parallel sets of beams, or plane trusses.

HANGER: A tie serving as a means of vertical suspension.

HIGH TECH: A late twentieth-century term for a design or interior with shapes, materials, and surfaces reflecting the latest developments in technology.

HUNCH: Of an arch, that part extending for some distance above the springing at each side.

IMPOSED LOAD: The load imposed on a structural element or structure by its users and environment. It is sometimes taken as external loads due to the wind, but here it is taken as including load less the dead load. In distinction to the latter, it has previously been called live load.

INERTIAL LOAD: A load that results from setting a body rapidly in motion or form any rapid change in its state of motion. It is proportional to the acceleration and the mass being accelerated.

INERTIAL RESISTANCE: An inertial load rearing as a resistance to an enforced acceleration.

IN-SITU: Constructed or carried out in the final location, referring most frequently to the casting of concrete structural elements in their final location.

JOIST: A name given to a simple timber or steel or precast-concrete beam of a floor or ceiling.
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<td>LINTEL (POST-AND-LINTEL)</td>
<td>A name commonly given to a single block of stone spanning horizontally over an opening or to a simple beam of some other kind, similarly used. Hence also the term Post-and-Lintel referring to the structurally simplest type of column-beam construction e.g.: Classical Hindu temples and Greek Buildings.</td>
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<td>LOAD</td>
<td>Often synonymous with force, but more general in that it can denote also the local intensity of a distributed force such as a pressure or a combination of forces such as a bending moment.</td>
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<td>MEMBRANE</td>
<td>A thin sheet-like structural element either flat singly-curved or doubly-curved and acting wholly in tension.</td>
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<td>MODERN ARCHITECTURE RESEARCH GROUP (MARS)</td>
<td>A group of progressive British architects and designers organized in 1932 and 1933 to represent Britain at CIAM meetings, to promote modern architectural ideas, and to conduct research.</td>
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<td>MODERN MOVEMENT</td>
<td>With beginnings in Europe c. 1900, &quot;modern&quot; architecture is that which is functional, rational, and nonhistorical. A second phase of modernism occurred in the 1930s, also the time when the Modern movement gained acceptance in the United States with the onset of the International style (sometimes used interchangeably with &quot;International Modern&quot;). In the 1960s and 1970s, a turning away from these values has been identified as Postmodernism.</td>
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<td>MOMENT</td>
<td>Of a couple, the product of the magnitude of either force and the moment arm.</td>
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<td>Of a single force about an axis the product of the component of the force acting at right angles to the axis and the moment arm.</td>
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<tr>
<td>MOMENT ARM</td>
<td>Of a couple the perpendicular distance between the two constituent forces. Of a single force about an axis, the perpendicular distance from the axis to the line of action of the force.</td>
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<tr>
<td>ORTHOGONAL</td>
<td>Intersecting at right angles.</td>
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<td>ORTHOTROPIC (ORTHOGONAL ANISOTROPIC)</td>
<td>Having different stiffnesses in two principal directions, usually in the direction of and at right angles to the principal span. An abbreviation of orthogonal anisotropic.</td>
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PINNED JOINT (HINGED): A joint between structural elements or components allowing them to rotate freely relatively to one another. Strictly, this calls for a frictionless pin to make the joint, but in practice some other kinds of joint including many riveted ones allow enough relative rotation with little resistance to be regarded as pinned. An equivalent joint in reinforced concrete is referred to as a Hinge.

POSTMODERNISM: A trend, appearing in the 1960s, away from the functional aesthetic of the International style and the severity of Brutalism, and favouring a return to historical references and individualized and emotionally satisfying solutions in architectural design.

PORTAL FRAME: The simplest rigid-jointed column-and-beam frame consisting of two columns spanned by a single beam rigidly joined to their heads.

PRESSURE: A distributed force such as that exerted by the wind, or the local or average intensity of such a force.

PRESTRESSED CONCRETE: Concrete that has had its internal strength increased by means of tensioning steel cables (tendons) before or after casting the concrete.

PRESTRESS: To apply loads by deliberately-controlled external means to a statically indeterminate structure of structural element in course of construction for the purpose of modifying beneficially the state of internal stress. This is tantamount to and may be seen as the means of, introducing deliberately undersized or oversized or members for the same purpose.

RATIONALISM: A philosophy in the eighteenth and nineteenth centuries, especially in France, favoring solutions in architectural design based on reason rather than tradition.

RATIONALIST MOVEMENT: An Italian branch of the Modern movement of the 1920s and 1930s, known in Italy as the Movimento Italiano per l'Architettura Razionale, or MIAR.

REACTION (Reactive Load): The counter-balancing load or set of loads brought into play by the action or active load on a structure or structural element.

REDUNDANT: Any, structural element whose introduction into a structure
| **ELEMENT** | makes its structural action statically indeterminate. It is usually possible to make alternative choices of the elements that are to be regarded as redundant. |
| **REINFORCEMENT** | A general term denoting some kind of addition to a structural element, usually another material for the purpose of improving its strength or stiffness. It usually refers to bars, cables, or prefabricated meshes of steel added to elements of concrete, and bonded or anchored to the concrete so as to act intimately with it. |
| **RESULTANT** | That single action (force or moment) that would be equivalent to it in effect. |
| **RIB** | A linear projection from the surface of a structural element, particularly, such a projection from the inner surface of a grid, vault etc. |
| **RIGID JOINT** | A joint between structural elements or components allowing them no relative rotation where they meet. In practice most joints in reinforced concrete and prestressed concrete when made in situ, and most bolted and welded joints in steel may be so regarded. |
| **RIGID-JOINTED FRAME beams** | A frame, particularly one composed of columns and to which overall rigidity is imparted wholly or largely by rigid joints. |
| **RISE** | Of a arch, shell or vault the vertical distance between the soffit at the crown, and the level of the springings. |
| **ROLLER BEARING** | A type of support incorporating hardened steel rollers set between hardened steel plates to allow free movement in one direction. |
| **SECTION** | A name commonly given to a rolled or extruded form of iron, steel or other material(s), characterized by a particular constant shape of cross-section such as I, T etc. |
| **SELF-WEIGHT** | The load on a structural element or structure due to the action of gravity of the element or structure itself. |
| **SHEAR** | A slipping or racking type of deformation which may be analysed into a contraction in one direction and an equal extension at right angles to it, and the type of structural action that leads directly to it. |
SIMPLY SUPPORTED SLAB SPACE FRAME SPAN SPREAD FOOTING STABLE STATICAL DETERMINANCY

Of a beam, supported at or near its two ends, in such a way that it is free at both of them to rotate in the plane of the loads, and at one of them to expand or contract longitudinally.

A structural element capable of spanning a horizontal gap in the manner of a beam, but extended laterally. It may also be capable, if suitable supported, of spanning simultaneously in a second direction.

A three-dimensional frame usually a triangulated one composed of struts and ties assembled in several families of intersection plane trussed so interconnected, that they all share, to some extent, in carrying any load.

A foundation in which the intensity of load imposed by wall on the ground is reduced by simply widening the base of the wall.

A characteristic of the structural action of a structure or any part of it that stems from an ability to carry a given set of loads in only way that is uniquely determined by the loads and the geometry of the structure or part. Hence also statically determinate. It should be noted that it is possible to scrutinize the structural action of most structures at different levels and that it may well be statically determinate at one level of scrutiny and statically indeterminate at a deeper level.
STATICAL INDETERMINANCY: A characteristic of the structural action of a structure or any part of it that stems from a potential ability to carry a given set of loads in a multiplicity of different, but equivalent ways, the action in a particular instance being dependent on relatives stiffnesses and the pre-existing internal loads or stresses resulting form the construction process and prior loadings etc., as well as on the set of loads considered and the geometry. Hence also called statically indeterminate.

STATIC LOAD: A load that is applied sufficiently slowly, and remains sufficiently constant, not to being into play any significant inertial resistances.

STIFFNESS: Resistance to deformation. More specifically the load, that is required to produce and is resisted by a given deformation.

In the case of a structure or structural element it is measure in terms of a particular type and pattern of loading and a particular characteristic deformation.

In the case of a structural material it is measured in terms of a particular type of stress action alone, and the characteristic associated strain.

STRAIN: A local proportionate deformation, or deformation per unit length. In the case of tension or compression. It is measured in the direction of the extension or contraction. In the case of shear it is measured, in effect, as the angular displacement of a line initially at right angles to the line or plane along which the shearing action takes palace.

STRENGTH: Ability to carry load(s). More specifically the maximum load that can be carried, before a chosen limit of behaviour is reached. In the case of a structure or structural element, it is measured in terms of a particular type and pattern of loading, and in the case of a structural material in terms of a particular type of stress or combination of stresses.

STRESS: The local intensity of an internal force measured acting perpendicularly (in the case of tension or compression) to or tangentially (in the case of shear) to a unit area of a given cross-sectional plane. Tensile and compressive stresses are also known as Direct Stresses.
A general term denoting the pattern or characteristics of some or all of the following: the forces acting on a structure or any part of it; the resultant internal forces and stresses; and the associated displacements, deformations, and strains.

A fully-formed unit of construction, which may be as small as a brick or bolt, or as large as a prefabricated section of a large steel box beam or a precast-concrete wall or slab. Thus it may be a self-sufficient structural element, or it may serve only as a part of such as element. It is identified essentially in terms of the construction or fabrication process rather than of the structural role.

A basic unit of construction self-sufficiently capable of carrying its self-weight and other loads to its supports. Arch, Beam, Column, Frames, Slabs, Strut and Tie—are selected structural elements, examples noted here.

A term used here to denote both the external geometric configuration (the form per se) of a structure or structural element, its ability to carry loads and withstand deformation, and its intended role in so doing. It, therefore, also embraces, either explicitly or implicitly, those details of the hidden internal configuration, the materials used, and the manner of construction or fabrication that together partly determine the response to loading or deformation.

A system of structural elements; Commonly, in the case of a building the complete system that plays the primary load-bearing role as distinct from infillings, finishes etc., that could be removed without significant loss of overall stiffness, strength or stability.

A structural element of relatively small cross-section acting like a column wholly or primarily in compression but, unlike the column not necessarily vertical, and usually forming part of a triangulated space frame or truss.

A straight slender structural element acting wholly or almost wholly in tension either as a hanger or as part of a triangulated space frame or truss.
TORSION: Twisting and the type of structural action that leads directly to it.

ULTIMATE STRENGTH: The maximum attainable strength under static load irrespective of the associated deformation, though in practice often taken, in the case of a complete structure, as the value of the load at which there would be a rapid loss of stiffness.

UNSTABLE: (1) Of a state of equilibrium, liable to be upset by a slight disturbance, as in the case of a pendulum with a rigid arm and with this arm standing precariously upright instead of hanging.

(2) Of a structure or structural element, being in a state of unstable equilibrium of on the verge of collapse.

WALL: A laterally-extended vertical structural element with a thickness comparable with or slightly less than, that of a column of the same height.

As a primary element, it serves, usually, as a vertical support and acts wholly or primary in compression, but it may additionally or alternatively—be loaded in shear.

YIELD STRENGTH: Measure of strength, when—to give-way to load(s) by plastic deformation.


A4. Principles of Similarity: Discussion

In architecture the transition from the heavy and closely spaced columns of Greek Temples (for historical background context) — through the moderate proportions of reinforced concrete structures— to the slenderness of structural steel frames has been accomplished principally, by the manifold up-grading of the strength of the respective material(s) of construction, now-a-days.

In view of Galileo’s preoccupation with scientific experimentation, it is not surprising — that he pioneered the theory of similitude. His blend of theoretical insight and experimental verification is still, after more than three centuries, the accepted method of contemporary science and technology.

The scientific approach to problems may be considered to comprise the successive stages: recognition, definition, compilation, analysis, synthesis and evaluation.

Analytical reasoning and conjecture play an important role throughout the process, but experimental research is often vital to a meaningful compilation of data and the sensible evaluation of hypotheses.

He emphasized that this scientific approach is directly applicable to the problems of architecture. Its appropriateness to some problems readily amenable to quantitative analytical consideration (e.g. structural design) is accepted, but its extension to the more qualitative aspects of architectural design (e.g. visual judgement) is only at its infancy. Nevertheless, a more systematic and rational approach to solving architectural problems is lacking, and thinking scientifically, may provide a more satisfactory convergence rate for design process.

This section is devoted to a discussion and presentation of the experimental methods and tools relevant to architecture, and it must be considered in the wider context of the scientific approach. Also in this section, principles of dimensional analysis and similarity pioneered by Galileo, and developed by later scientists and engineers— to become accepted basis for model design and interpretation.

In the theory of dimensional analysis the principle of dimensional homogeneity between the physical quantities appearing in an equation is of fundamental importance. Its validity is regarded here as axiomatic.

Further, dimensional theory is also used in reducing the number of variables or parameters in order to achieve an economy of experimental effort.
Dimensional analysis approaches a problem with complete generality and does not require knowledge of the physical laws governing the problem. It is used to derive the conditions of similarity; however, in many problems the governing large are well known, so that they can be used to determine the conditions of similarity. In general, three classes of similarity are required for solving the prototype problem, satisfactorily.

The prototype behaviour is specified by its parameters. If its governing equation is known from a theoretical analysis, it forms an explicit mathematical representation, or model, of the prototype. If it is amenable to an analytical solution for the given boundary conditions, then a theoretical prediction of the prototype response is obtained. This is a powerful method, particularly since the introduction of digital computation.

When the governing equation of the prototype, though known, is not suitable for an analytical solution, a model is used. This must belong to the same class of systems as the prototype, but may be based on either physical or mathematical similarity. For physical similarity, a physical model is constructed which has the same governing equation as the prototype. Mathematical similarity can be satisfied either by a dissimilar or analogous model.

If the governing equation is wholly or partially unknown, only physical similarity can provide a solution, a physical model is then indispensable.

At the other extreme end of the similarity scale is the descriptive model for specifying a problem not expressible in quantitative terms.

Perfect similarity is seldom obtainable as it is often necessary to introduce approximations. For example, in order to achieve practical results, approximations may have to be applied in the mathematical formulation and solution of the mathematical model or in the construction, testing and interpretation of a physical model. Instances readily coming to mind are the neglect of shear strain in the ordinary bending theory; relaxation methods for numerical solutions of analytical problems; and employing a plastic material to model reinforced concrete.

If all similarity conditions are fulfilled, a true model is produced. Approximate similarity is achieved by distorted models which are often quite adequate for their particular tasks. If the degree of distortion is large, extrapolation of model results is prone to uncertain errors, and some auxiliary investigations may then be necessary in order to define the confidence limits and conditions, under which results are acceptable.

Figure. A5.1: Reference for Equivalent UDL Conversion for Select Symmetrical Loading

Figure A5.1.1: Reference for Equivalent UDL Conversion for Select Asymmetrical Loading

(1) \[
\begin{align*}
E & \quad \text{TOTAL LOAD (W)} \\
\end{align*}
\]
\[
\begin{align*}
\frac{W}{4} & \quad L \quad \frac{3W}{4} \\
\end{align*}
\]
\[
\begin{align*}
\rightarrow & \quad \sim \frac{3X}{2} \\
\end{align*}
\]

(2) \[
\begin{align*}
E & \quad \text{W} \\
\frac{W}{8} & \quad L \quad \frac{7W}{8} \\
\end{align*}
\]
\[
\begin{align*}
\rightarrow & \quad \sim X \\
\end{align*}
\]

(3) \[
\begin{align*}
W & \quad \frac{L}{3} \\
\frac{W}{3} & \quad L \quad \frac{2W}{3} \\
\end{align*}
\]
\[
\begin{align*}
\rightarrow & \quad \sim X \\
\end{align*}
\]

(4) \[
\begin{align*}
E & \quad \text{W} \\
\frac{W}{4} & \quad L \quad \frac{3W}{4} \\
\end{align*}
\]
\[
\begin{align*}
\rightarrow & \quad \sim \frac{9X}{2} \\
\end{align*}
\]

(5) \[
\begin{align*}
E & \quad \text{W} \\
\frac{W}{8} & \quad L \quad \frac{7W}{8} \\
\end{align*}
\]
\[
\begin{align*}
\rightarrow & \quad \sim \frac{3X}{4} \\
\end{align*}
\]
Figure A5.2: Types of Loading in General

Programmatic requirements for building

Occupancy loads and requirements

Environmental forces and requirements

Structural System: basic morphological response

Other building systems

Site and other conditions

Construction, and other related rational considerations

Figure A5.3: Basic Factors Effecting the Development of Structure System in General

Figure. A5.4: Select Member End Actions and Local Co-Ordinate System