ISSN: 0974-5823 Vol. 6 No. 3 December, 2021

International Journal of Mechanical Engineering

CATENARY BASED FERRO CEMENT THIN SHELL: CLASSIFICATION OF STRUCTURAL SYSTEM

Atul Setya

Research Scholar, Sushant School of Art and Architecture, Sushant University, Gurgaon, India

Dr. Tejwant Brar

Senior Professor, Sushant School Art and Architecture, Sushant University, Gurugram, India

Abhishek Kumar Srivastava

School of Architecture, Galgotias University, Greater Noida, India

ABSTRACT

Structural innovations are the product of architectural design process with respect to resistance to nature and other threats. These products became template for others structure or may be help for generating other form by some geometrical or other phenomenal combination. These products can be defined as system on various magnitude such as adjustment/ confinement/ dissection/ dispersion and collection of forces, form and space geometry etc. In this paper we will try to cover all possible magnitudes and resulting classification of structural systems.

INTRODUCTION

What is Structural System?

Throughout architecture, structure occupies a role that attributes both nature and supports shape.

The structure of material forms such as house, machine, tree or animate beings is most essential among the basic conditions that contribute to the existence. Material forms cannot be preserved without structure, and the very destination of the form object cannot assert itself without form preservation. Therefore, it is a fact: no performing complex, animate or inanimate without material structure.

In architecture, structure assumes a fundamental part

- Structure is the primary and solitary tool for the generation of architectural form and space. Because of this function, the struct333333ure becomes the essential means of shaping man's material environment.
- Structure is based on the discipline practiced by natural science laws. Structure therefore ranks as an absolute standard among the formative powers of architectural design.
- Structure, however, commands an infinite scope for understanding in its relationship to architectural form. The architectural type can fully conceal the structure; it can also become the building itself, the architecture.
- Structure personifies the designer's creative intent to unify shape, material, and strength. Structure therefore provides an aesthetic, inventive medium for both shaping and building experience

So conclude from this: structures define buildings in basic ways: their source, their being, their effect. An integral part of genuine architectural design is therefore the creation of structural principles, i.e. basic structural design. Consequently, the prevalent distinction between structural design and architectural design, as to its goals, its methods, its rating and, in that respect, its performers, is unfounded and undermines the purpose and concept of architecture.

It is important to eliminate the distinction between architectural design and structural design.

But the problem is

The architects design buildings in aloofness of the poetry of structural forms due to either ignorance or antipathy. It is only too easy to ignore the elegance and precision of structures in modern architecture, or even the utter lack of them. The architects, confined to the task of making stand, keep and last given architectural structures, cannot take their creative potential to any architectural effect on both, the development of modern architecture or the invention of new prototypical structural systems.

How can the effects of these issues be handled, solved or at least alleviated?

The best way to make complex subject areas available is to classify their content: systematics. Systematization means identifying, articulating and disclosing content in accordance with a governing principle of order. Such a principle is conclusive if it derives from the very essence and application of the subject matter itself.

There are some typical mechanisms in nature and technique for dealing with acting forces, i.e. redirecting them. They are basic; they have intrinsic characteristics; in their daily encounter with forces they are familiar to man, how to bear them, and how to react.

- ADJUSTMENT to the forces
- DISECTION of forces
- CONFINEMENT of forces
- DISPERSION of forces
- COLLECTION and GROUNDING of forces

The material environment consists of OBJECTS, single and in conjunction, macrocosmic and microcosmic, animate and unanimous, grown and built. According to the source of their origin, there are two categories of them, the natural objects and the technical objects operate through their FORM. The consistency that ensures object perpetuation against forces is called STRUCTURE, the form that follows structures are material patterns that preserve object functions in man's natural and technical environment.

1.1 SIGNIFICANCE OF STRUCTURES IN MATERIAL ENVIRONMENT

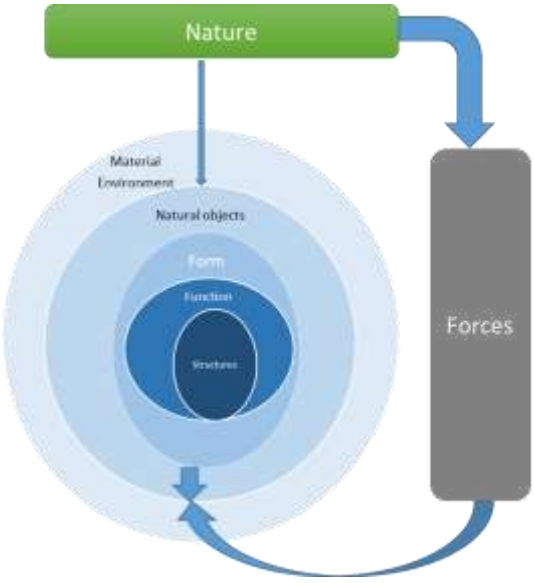


Figure 1 Structure Material and Forces in Nature

The material environment consists of OBJECTS, single and in conjunction, macrocosmic and microcosmic, animate and unanimous, grown and built, two categories of NATURAL objects and TECHNICAL objects exist according to the source of their origin. (Elliot, 1992)

Objects operate through their FORM Therefore, form always has FUNCTION, i.e. form preservation is a prerequisite for function perpetuation.

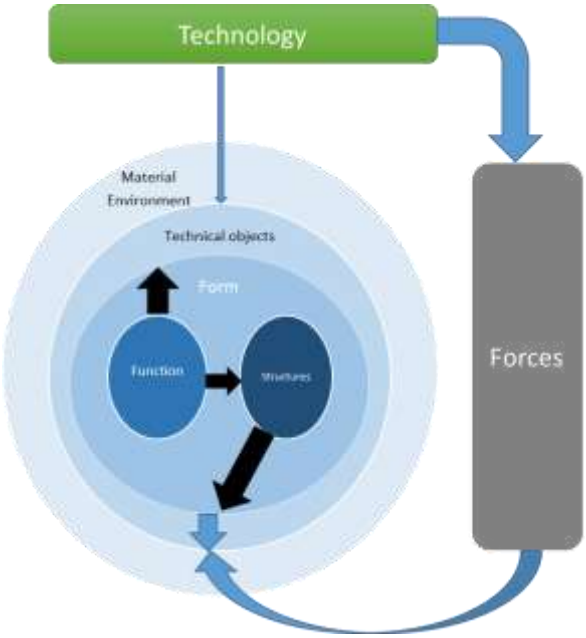


Figure 2 Structure, Form, Material and Forces in Manmade technology

All objects are subjected to forces. The consistency that ensures object perpetuation against forces is called STRUCTURE, the form that follows structures are material patterns that preserve object functions in man's natural and technical environment.

1.1.1 STRUCTURAL SIGNIFICANCE: RETAINING OBJECT FUNCTIONS

Man's material world is composed from objects, single and together, animated and inanimate, grown and built. There are two groups according to their origin: the natural objects and the scientific ones.

Also, the elements of which the single object is composed are objects as in reverse the larger structure again appears as structures in which several individual objects co act as one. That is to say, a particular magnitude does not belong to the material objects. They are both macrocosm and microcosm components. As an idea, we grasp all of the material environment's definable solids. (Ackermann, 1991)

Through the form unique to them, all material objects in nature and technique manifest themselves. Form in the corporal realm is the distinctive three-dimensional distribution of the object substance. It is geo-metric.

The specific function is linked to the particular shape. Therefore, if the form is invaded or annihilated, the functions will also be affected as well. Therefore, preserving the form is a prerequisite for the perpetuation of functions in the material environment. (Fisher, 1964)

Each material form is inevitably exposed to the action of gravitational forces (weight), i.e. the object as represent by that form. Other force actions come first from the object's function, second from the sub-stance's characteristics and articulation, and finally from the surrounding conditions.

Therefore, the statement is valid: the material forms of the environment will remain themselves only through their structures and can thus fulfil their functions. Structures are the very preservation in nature and technique of the functions of the material environment. (Engel, 1981)

1.1.2 ACTION OF STRUCTURE: FLOW OF FORCES / REDIRECTION OF FORCES

The purpose of the bearing process, how-ever, is not the re-receiving loads ' very transparent operation, but the transmission mechanism internally working. A solid cannot withstand, not its own (dead) load, and even less additional (live) loads, without the ability to transfer and discharge loads.

The structure therefore works in three successive operations as a whole:

- Reception of Load
- Transfer of Load
- Discharge of Load

This cyclic process is called the FLOW OF FORCES. For the design of a structure, it is the basic conceptual image, it is its basic idea. It is also a measure of the structure's economy as a path of forces.

The movement of forces does not pose problems as long as the shape of the object follows the direction of the forces acting. In the case of gravitational loads, there would be such a situation if the substance is connected to the Earth, the point of discharge, in the most direct and shortest route. If the flow of forces does not take such a direct route but has to accept detours, a problem will arise, how-ever. (Boaga & Boni, 1965)

The task is to change the' picture' of performing forces by means of material substance into a new' picture' of acting forces with overall equal potency, whether by altering the functional form itself, by strengthening the form substance, or by additive structure.

But then such a new' picture' of forces will be created less by changing the magnitude of forces than by re-establishing the direction of forces. Indeed, it is the latter measure that determines the magnitude of forces within the object acting.

The very precondition under which new' pictures' of forces will emerge is to change the direction of forces. In other words, force transport must be conducted along new routes, it must be redirected. Therefore, REDIRECTION OF FORCES is the principle for controlling the flow of forces within the object. (Burgess & Pasini, April 2004)

1.2 NATURAL AND TECHNICAL STRUCTURES: EQUALITIES

Technical structures in the realm of nature provide analogies, parallels and similarities with the structures. This seems rational: man has always used nature as a model in his effort to shape the environment to suit his goals. Science and technology are descendants of nature exploration.

Nevertheless, the connection of natural and technological structures is based less on the regional closeness of man and nature, but rather on the existence of two fundamental identities of families

-both structural families serve the purpose of safeguarding material forms against acting forces.

-Both structure families fulfil this purpose on the basis of the identical physical laws of mechanics.

In terms of the mechanical process: structures in nature and technique both effect a redirection of the oncoming forces in order to preserve a definite shape in a definite relation to the function. Based on the two principles, both execute this identically: the flow of forces and the equilibrium state.

Because of this and causal. Instrumental identity the structures of natural objects in the development of technical structures are legitimate models of comparison. In the first place, they are important sources for learning about the function, shape and structure linkage. (Chilton, 2000)

1.2.1 NATURAL AND TECHNICAL STRUCTURES: DIVERSITIES

The main reason for discerning between the two structural groups, both as a corporeality and as a notion, is provided by the difference in their origin:

Nature: growth - mutation – fissure-fusion - evolution - decay

= separate individual processes, out of itself occurring, temporally continuous or periodical

Technique: design - analysis - implementation - production - demolition

= indispensable process constituents, instrumentally occurring, interdependent, temporally finite (i.e. momentous)

However, as integrated forms for both the function of the object and the management of forces, nature structures present classical directives and ideal examples of efforts in the development of buildings to resolve the existing separation of technical systems: construction structure, space enclosure, services, communication. We demonstrate above all the great potential of layout found in the creation of types of synergetic structure. (Blockley, 2009)

The material world consists of OBJECTS, single and in combination, macrocosmic and microcosmic, animate and unified, grown and created, two types of NATURAL objects and TECHNICAL objects exist according to the source of their origin.

Objects function through their FORM Therefore, form always has FUNCTION, i.e. preserving the form is a prerequisite for perpetuating function All objects are exposed to forces.

The consistency that ensures object perpetuation against forces is called STRUCTURE, the shape which follows structures are material patterns that maintain object functions in man's natural and technological environment.

1.3 INTERPRETATION OF ARCHITECTURE AS PART OF THE ENVIRONMENT

Architecture is the Technical space of the physical environment. 'Technical' in this context means the quality of "being shaped-by-man', i.e. of 'not-having originated-out of-itself'

Disclosure of a MAN, environment CONFLICT is the causality of planning in general. In the case of architecture A conflict exist, if the built-environment, The 'technical space:, does not comply, or merely incompletely, with) certain wants of. Man

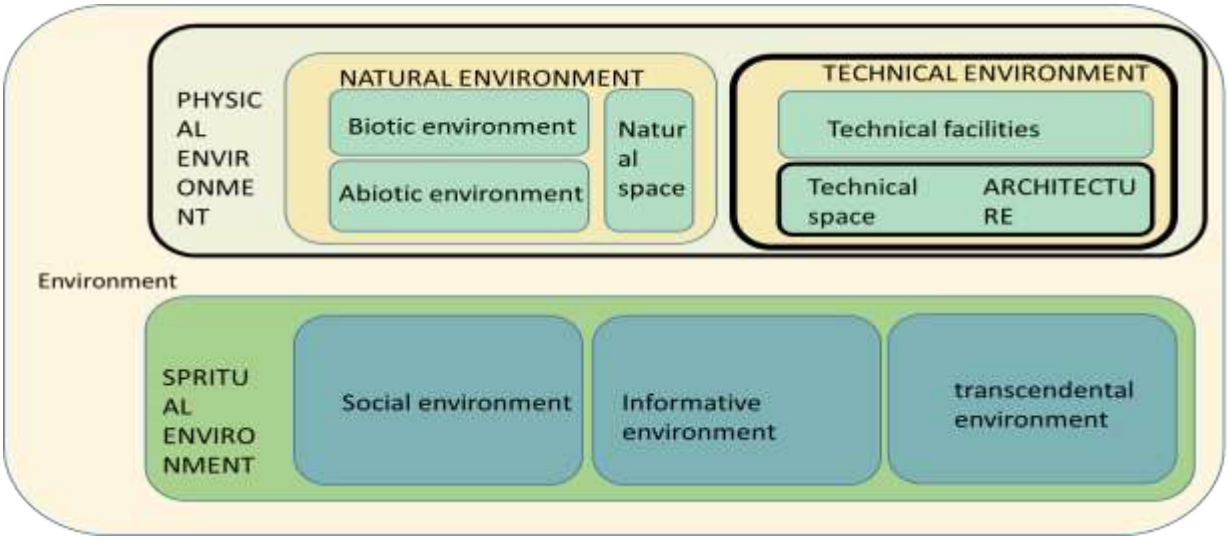


Figure 3 INTERPRETATION OF ARCHITECTURE AS PART OF THE ENVIRONMENT

Planning in architect is initiated with through the definition of the planning project. It manifests itself as a sequence of three major phases.

Construct the OBJECTIVE PATTERN

Design of System and FORM SPACE CONFIGURATION

Development of TECHNICAL CONTROL SYSTEMS

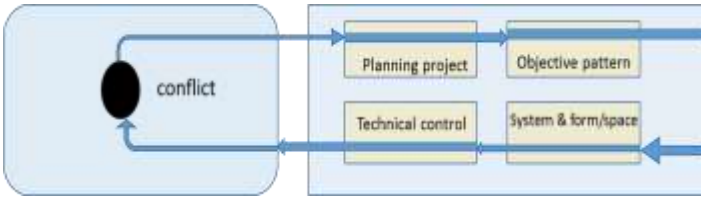


Figure 4Casulaity of Planning in Architecture

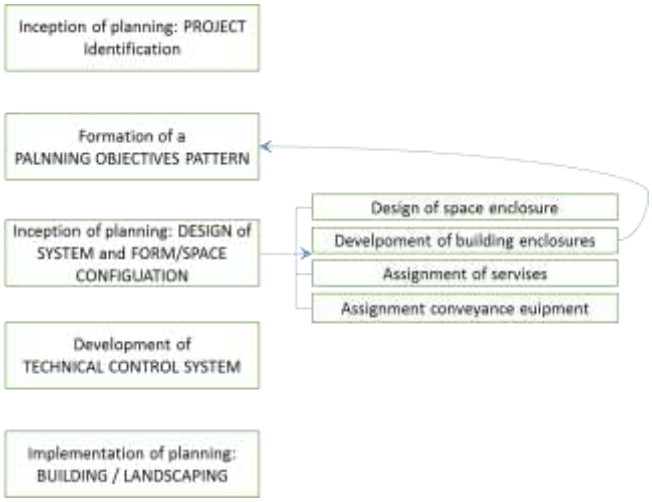


Figure 5 Sequences of planning process in architecture

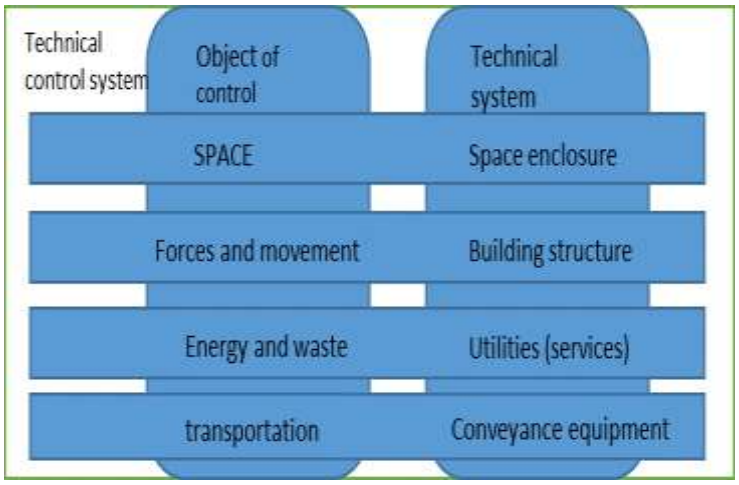


Figure 6 Position of Structure Design in process of planning in architecture

1.4 POSITION OF STRUCTURE DESIGN IN PROCESS OF PLANNING IN ARCHITECTURE

Structure design is the linear planning process in architecture as rule can work only after the form/space configuration has been conceived

Through feedback is guaranteed that form impulses of structure design will become fully effective in phase of form/space design (Coucke, Jacobs et al. September 16–18 1998)

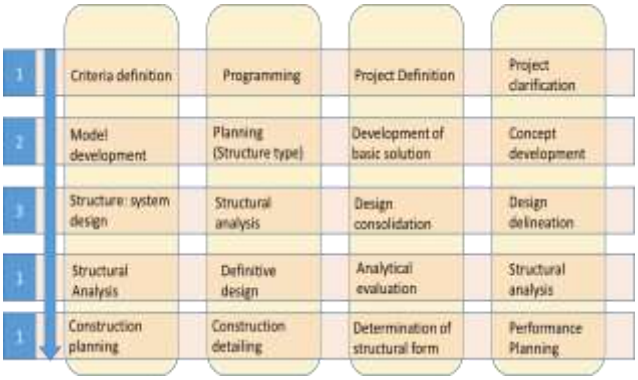


Figure 7 Major phases of structural design

1.4.1 FUNCTION AND SIGNIFICANCE OF STRUCTURES

Structures and systems

Structures in nature and technique essentially serve the function of sustaining physical form. Preservation of form is prerequisite to the performance of system: engine / house/ tree 1 man + without structure no system

The function of the socio-technical system 'building basically rests upon existence of defined space, Space is defined by its enclosure, Author of space enclosures is structure + without structure no building.

General principle for the design of structural system

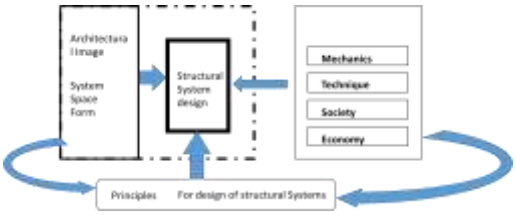


Figure 8 interrelationship of major determinants in design process

From the interrelationship of major agents that determine system, form and function of structures, universally valid principles for the design of structure systems can be derived

1	Compatibility with, and qualification for enhancement of, the prime idea of the architectural design	FORM DESIGN principles
2	Appropriateness of ranking within the concert of architectural bin generators	
3	Potential for optimization or re-evaluation in the design of The building shape	
4	Three-dimensional reality of structural behaviour structural design	STRUCTURAL principles
5	Straightness and logic of the flow of forces from load reception to load discharge	
6	Identification of system for stabilization against horizontal and asymmetrical loading	
7	Preference of statically indeterminate systems (versus determinate systems)	
8	Regularity of structural articulation and symmetry of structural component functions	ECONOMICAL principles
9	Balanced stress distribution amongst members of equal or related structural functions	
10	Imposition of two or more structural functions on the single component member	

Figure 9 Design Principles: - criteria for quality of structural systems

1.5 CONTENT AND DEFINITION CRITERION OF STRUCTURE AND STRUCTURAL SYSTEM

The structure system is defined by 2 system components, each effecting tie others

1 FORCES= Dynamic system of load transfer and control of forces

2 GEOMETRY: Descriptive system of structural form and path of forces. (Holgate 1986)

In case dike corporeal structure one more definition component is instrumental

3 MATERIAL= Material system for control of forces and effectuation of geometry

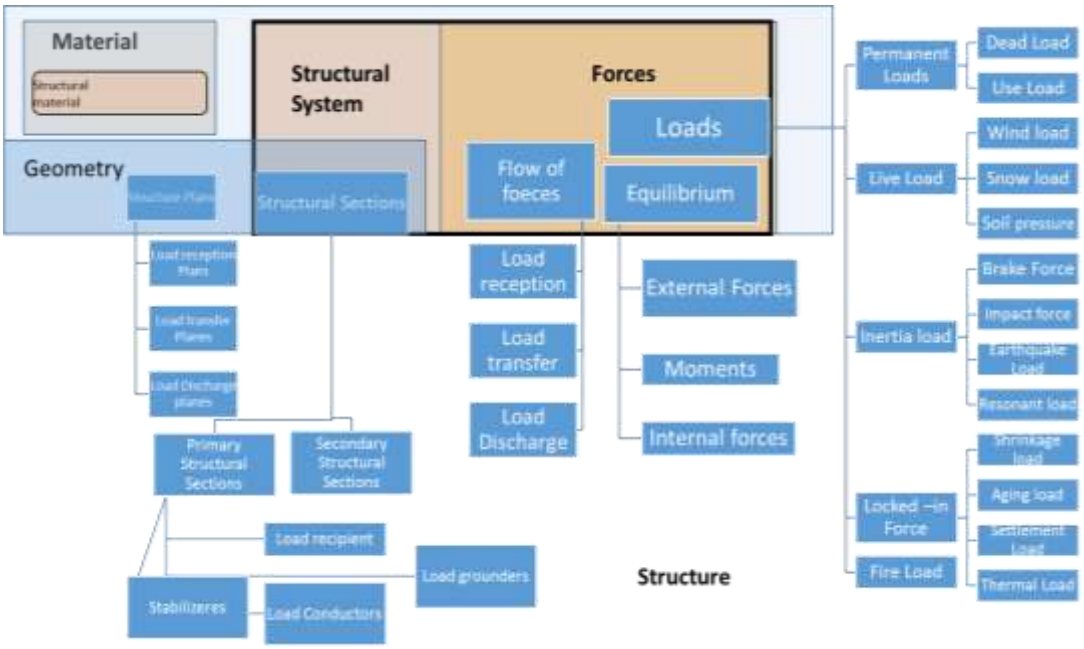


Figure 10 Conceptual relationship between building and StructureDiversity of forces in structures / Denominations

1	Kinds	External Forces	Internal Forces	Sectional Forces	Active forces	Reactive force	Resistant Forces	Gravity Forces	
2	Stress	Compres.	Tensile	Thrust	Shear	Torsion	Bending	Fiction	Membrane Forces
3	direction	Horizontal Forces	Vertical Forces	Oblique	Transverse Forces	Normal Formal			
4	Distribution	Point Forces	Linear Forces	Planer Forces	Spatial Forces				
5	Duration	Static Forces	Dead Loads	Live Loads	Dynamic Forces	Moving Forces	Resonant Forces		

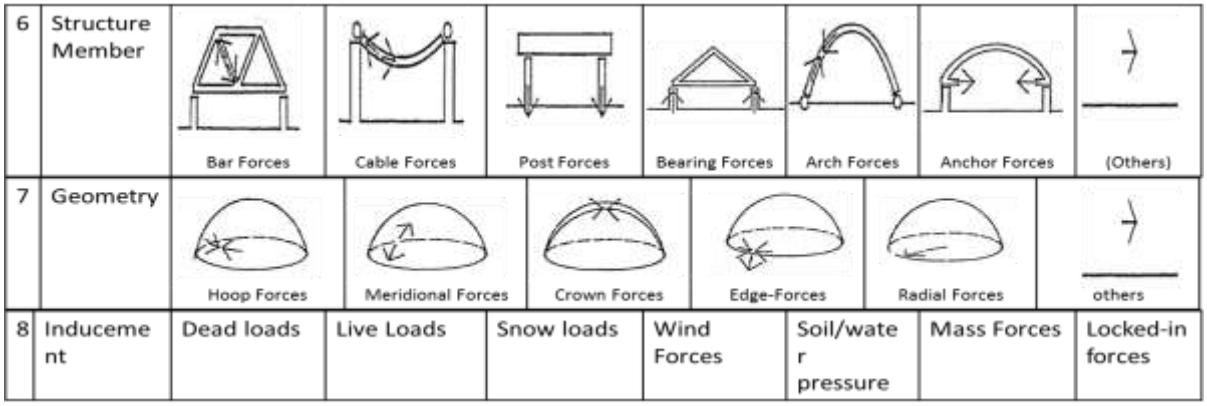


Figure 11Diversity of forces in structures / Denominations

Structures are devices for constraining and steering force. These forces are obtained by 4 condition specific to building.

- Its live (utilitarian) loads and building's Weight.
- Kind of usage (consequence of operation) of the building
- Characteristics and building articulation of building substone
- Influence and spatial condition of its surrounding

Two conception about the operation of forces guide the design of structure

+force 'FLOW' through the structure and are discharged to the earth.

+forces 'stay fixed' in equilibrium through counter forces and are static.

1.5.1 PREREQUISITE OF THEORY OF STRUCTURES

The central subject in the creative design and analysis of structures is FORCES in EQUILIBRIUM A structure image is to be designed and dimensioned that resists the active forces, te. mobilizes opposite forces which secure the equilibrium. (Heyman, 1998)

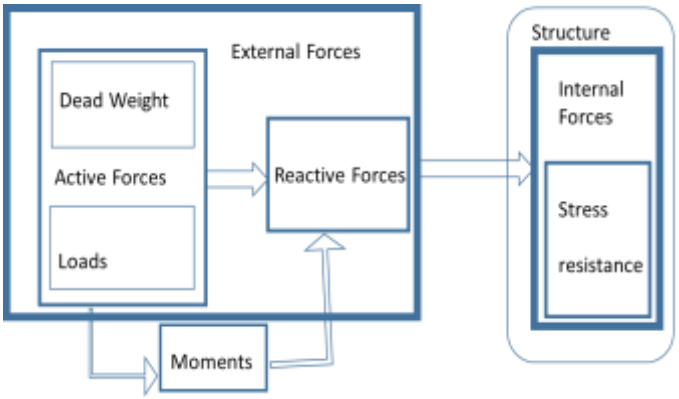
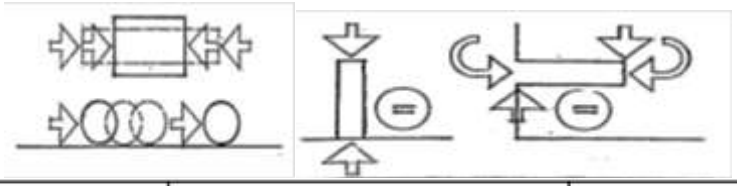


Figure 12 Forces in Equilibrium

1.5.2 ESSENTIAL CONCEPTS IN BEHAVIOR OF STRUCTURES



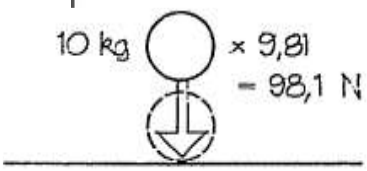
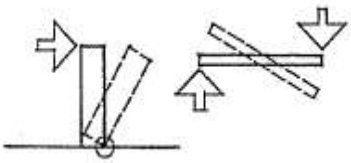
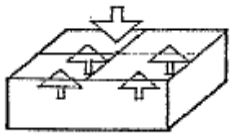
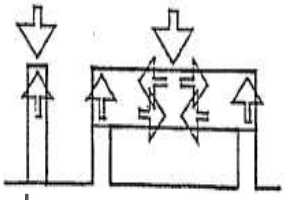
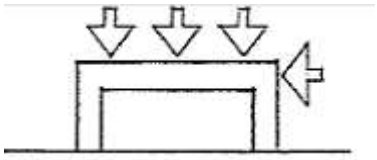
	FORCE is a quantity which induces a solid to move or to change its state (or its shape)	Force = m X a N/kN Force = mass X acceleration
	LOADS are the forces that act upon a solid forces from the exterior excepting, the reactive forces emanating from the solid bearing	L=FA=m X A N/kN Load= Active Force
	GRAVITATIONAL FORCES is the Force by means which the mass of the earth pulls a solid commensurate to the quality of its mass / =weight	G= m X 9.81 m/S2 N/kN GRAVITATIONAL FORCES= Mass X gravitation
	MOMENT is the turning motion induced by a couple or exerted by a force on a solid of which the center motion lies outside the direction of force	M = F X L (kN) Nm Moment = force X learn arm
	STRESS is the internal (resistant) force per unit area which is mobilized in a solid through the action of an external force	σ = F / A (kN) N/cm2 Stress = Force/Area
	RESISTANCE is the force by means of which a solid withstands a defomation or motion induced by the action of an external force / = resistant force	R=FA=m X A N/kN RESISTANCE= RESISTANCE Force
	EQUILIBRIUM is the state in which the sum total of forces acting upon a solid does not produce any motion, meaning that it is equal zero	$\sum$ F + M =0 Sum total of forces and moments=0

Figure 13 Essential Concepts in behavior of structures



1.6 THEORY OF STRUCTURES: SUBJECT, REFERENCES AND ARTICULATIONS

Levels of structure concept = Definitions

A) Structure image,

- Characteristic form of that building substance, which grant and preserves the
- Determinant-geometry that vender's material the architectural form /space, concept

B) Structural System

- Operational and pictorial scheme, for redirection and transmission of forces in the building
- basic geometry for the mechanics of equilibrium of forces with in building

C) Structure

- Sum total of all parts of the building, that perform bearing functions
- Substantiated structure system
- One agent of the building's essence that grants preservation of form and fulfillment of function

D) Structure fabric

- Technological reality of the building structure as autonomous engineering construction
- Technical fabric for controlling forces that act on the building, functioning as both, complex of individual parts and integral mechanism

E) Structure pattern

- Internal articulation of the structure fabric (Coutts & Grace, 1995)
- Ordering disposition for the interconnection of individual structural members of the building.

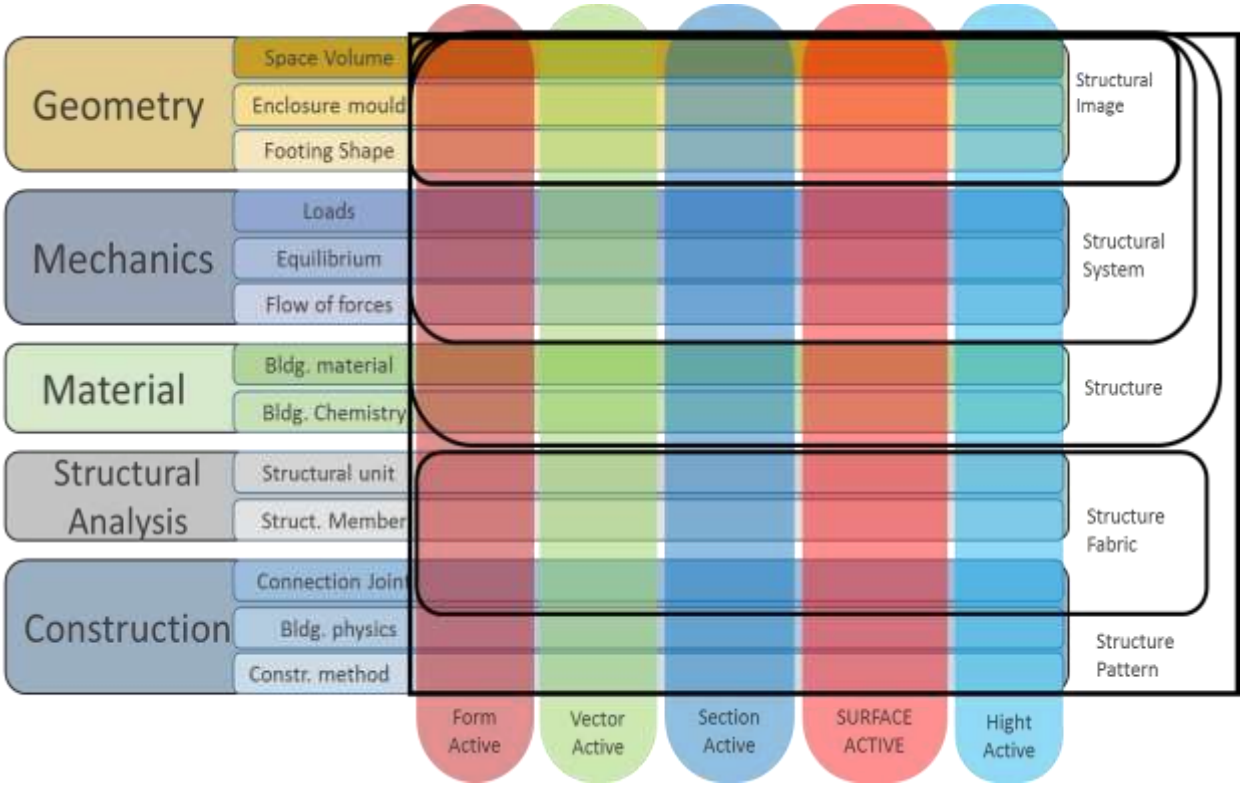


Figure 14 THEORY OF STRUCTURES: SUBJECT, REFERENCES AND ARTICULATIONS

1.6.1 CAUSALITY AND FUNCTION OF SPACE IN A BUILDING

The activities of man essentially unfold upon horizontal plane and therefore predominantly require for the enclosed space the horizontal extension.

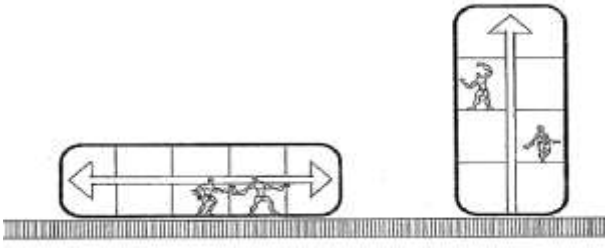


Figure 15 Space and Activity of Man

The activities of man require spatial height not only for freedom of movement, lout especially for the increase of use area on the planet. (Fuller, 1983)

The substance of space enclosure due to gravitational pull and activity dynamics of man is primary cause for the necessity of structures in building.

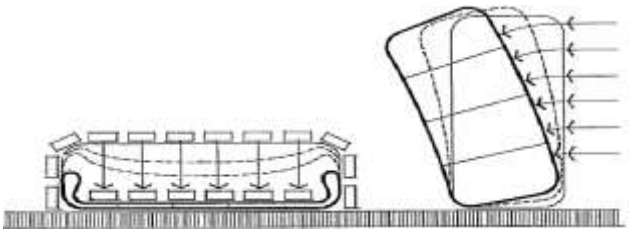


Figure 16 challenges

The vertical extension due to increasing wind load exposes space enclosure to horizontal dynamics that tends to change the geometry of space volume.

The conflict of two directions of gravitational pull and activity dynamics of mains primary cause for the necessity of structures in building.

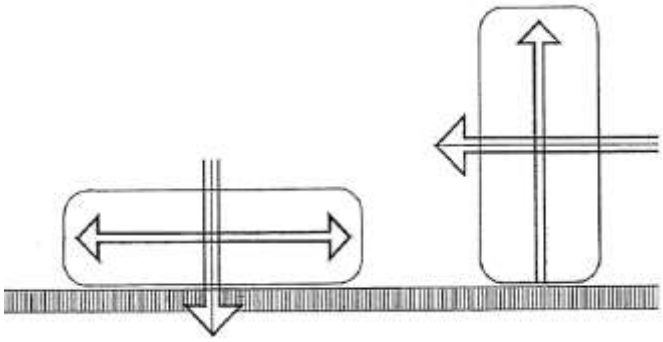


Figure 17Conflict

The conflict of two directions of wind load and height extension of enclosed is the second cause for necessity of structures.

Through structures the acting gravitational force will be redirected into horizontal direction and according to the requirement of the space volume, will be grounded. (Hunt, 1997)

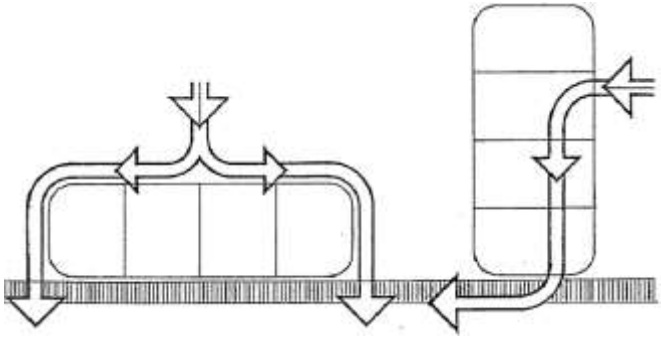


Figure 18 Function

Through structures the acting wind forces will be redirected into vertical direction and according to the requirements of the space volume will be grounded.

1.6.2 CENTRAL IDEA AND CRITERION FOR THE FORMATION OF A STRUCTURE SYSTEMATICS.

Complex subjects' fields are best made accessible through classifications of their contents: SYSTEMATICS.

The systematics of a subject field is rational if it is derived from the very ESSENCE OF THE SUBJECT ITSELF.

The essence of structure is its function: REDIRECTION OF FORCES

1.6.3 SYSTEMATICS OF STRUCTURES IN BUILDING

For the redirection of acting forces through substance nature and technique hold 4 distinct mechanisms:

- Adjustment to the forces - FORM action
- Dissection of the forces - VECTOR action
- Confinement of the forces - CROSS SECTION action
- Dispersion of the forces - SURFACE action

In the building is to be added as a diametrical- atypical-mechanism:

- Collection and grounding of loads - HEIGHT action

The seizure of the domain of structure and the creative application of their formal and spatial idioms in architectural design therefore require

- Knowledge of the mechanisms that make forces change their directions
- Knowledge of valid structure geometries for generation of form and space.

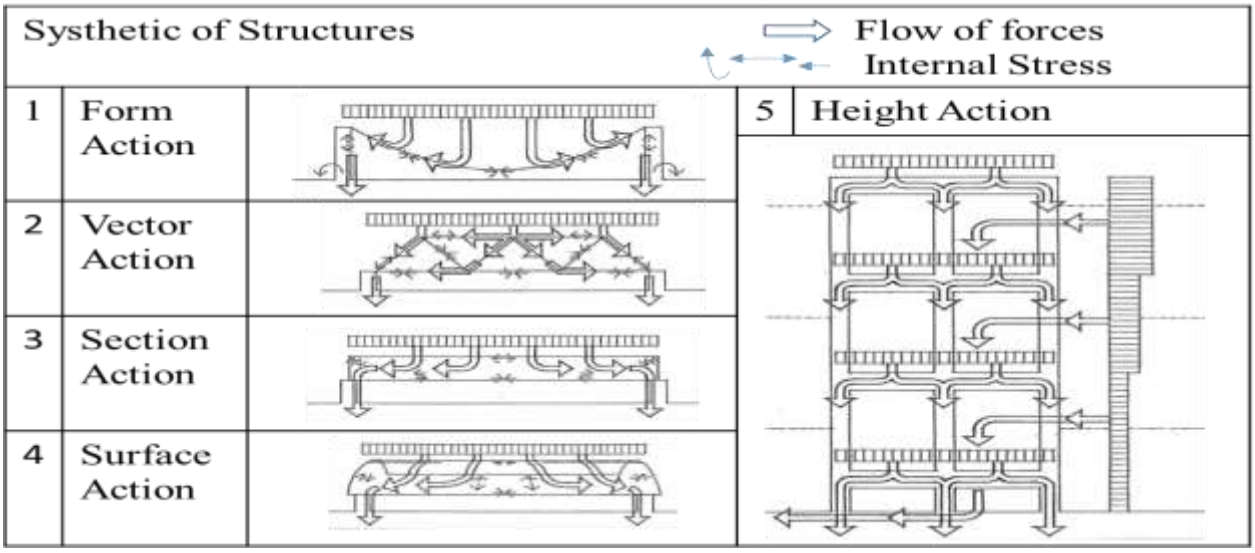


Figure 19 SYSTEMATICS OF STRUCTURES

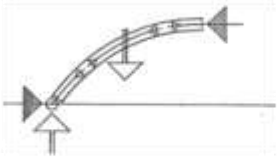
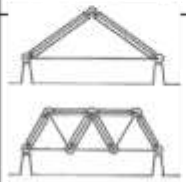
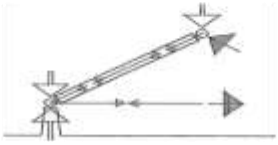
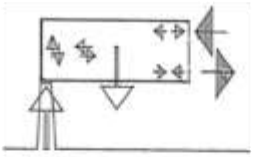
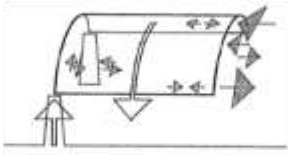
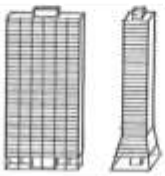
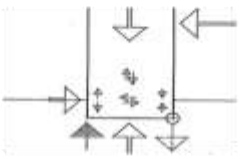
Criterion		Prototype	Forces	Feature	Mechanics of Redirection of forces	Structure Family
1	Form	 Funicular arch Suspension cable Circular ring Balloon	Compression or tension	Thrust Line Catenary circle		Form - Active
2	Vector	 Triangular truss Trussed beam	Compression or tension	triangulation		Vector - Active
3	Cross Section	 Beam Frame Flat Slab	Bending section forces	Sectional profile		Section - Active
4	Surface	 Plate Folded slab Cylindrical shell	Membrane stress	Surface form		Surface - Active
5	Height	 Slab tower	(Complex conditions)	Load grounding stabilization		Height - Active

Figure 20 Classification of Structural System in Buildings

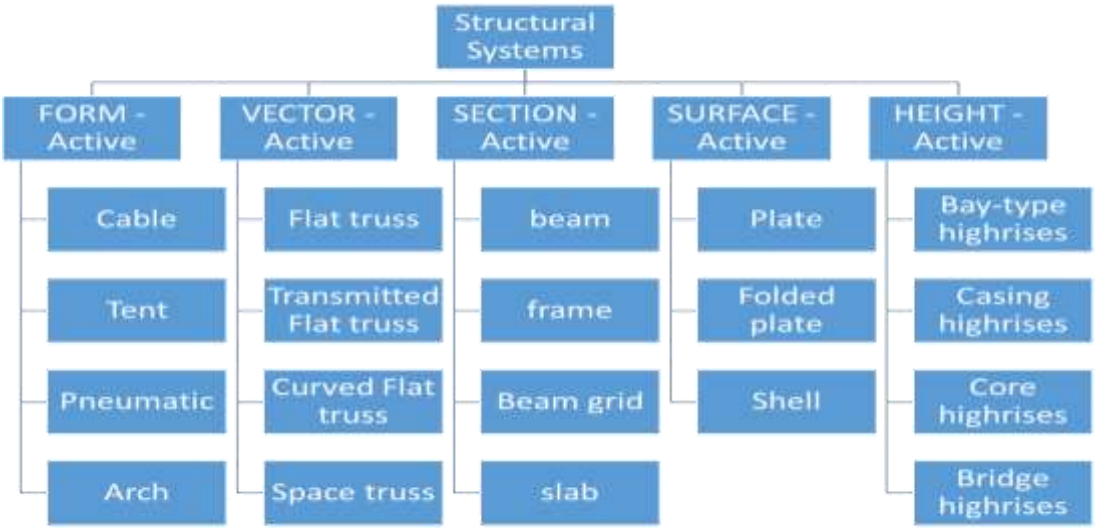


Figure 21 Classification of Structural System in Buildings

1.7 GUIDE PRINCIPLE TO THE CLASSIFICATION OF STRUCTURES

Disposition		Guide Principle	Examples					
Level 1	Structure FAMILY	Mechanism of redirection and transfer of forces	FORM-Active Structures		SECTION-Active Structures		HEIGHT-Active Structures	
Level 2	Structure TYPE	Configuration or common object denomination	ARCH Structures	ARCH Structures	FRAME Structures	BEAM GRID Structures	CORE highrise	BRIDGE highrise
Level 3	Structure Single	Geometric or constructional feature	Thrust lattice	Peak tents	Storey frames	Gradated grids	Indirect load cores	Storey bridges

Figure 22 GUIDE PRINCIPLE TO THE CLASSIFICATION OF STRUCTURES

1st level: 5 structure FAMILIES

The characteristic mechanism of redirection and transfer of forces form the basis for the major subdivision of structure into 5 system 'families' (with new denominations for each 'family'

2nd level: 19 structure TYPES

The subsequent subdivision into structure types makes use of the conventional denominations of structures that are derived from the configuration from the technical composition or from the characteristic's structural element

3rd level : 70-80 structure SINGLES

THE final differentiation rests upon the dominant geometric or constructional feature of the structure body, It presents a comprehensive order of model structures that constitute an essential forms discipline in the design. (LeDuff & Jahchan, 2001)

So we can say

1.8 STRUCTURAL SYSTEM IN COACTION: HYBRID SYSTEM

1.8.1 DEFINITION

Hybrid structures are systems, in which the redirection of forces is effected through the coaction of two or served different- lout in their efficacy basically equipotent- systems from different structure 'families'

The coaction is gained by two possible forms of systems linkages:

SUPERPOSITION or COUPLING

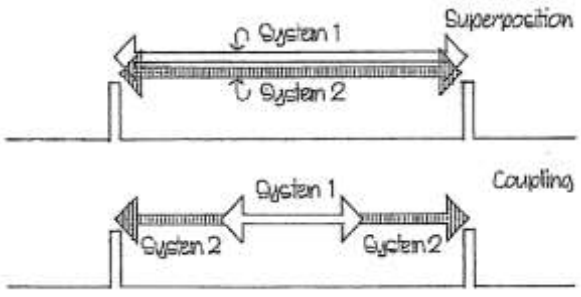


Figure 23 The coaction is gained by two possible forms of systems linkage

1.8.2 INCORRECT 'HYBRID' DENOMINATION

Hybrid structure systems are NOT to be understand as those systems, in which component bearing functions such as load reception, load transfer, load discharge, wind bracing or other stabilizations are performed by constructions each belonging to a different structure ' family'.

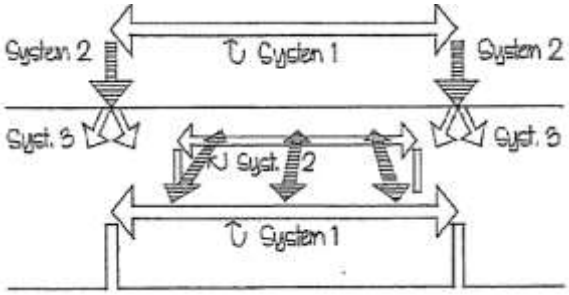


Figure 24 INCORRECT 'HYBRID' DENOMINATION

1.8.3 POTENTIAL OF HYBRID STRUCTURE

Mutual compensation or reduction of critical forces

Example: Opposite horizontal forces at bases of funicular arch and suspens, cable

Twofold or multifold structural function of single structure members

Example: Function of upper chord resp. of rafter as beam and as compression bar

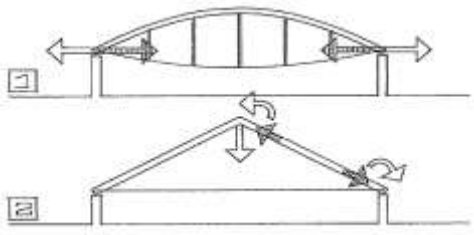


Figure 25 Function of upper chord resp. of rafter as beam and as compression bar

1.8.4 EXAMPLES OF HYBRID STRUCTURES

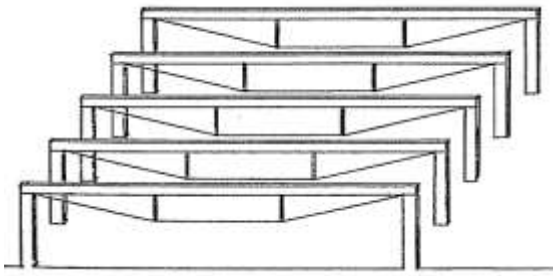


Figure 26 Cable Supported beam: Superposition of SECTION active and FORM Active Structural systems

Cable Supported beam: Superposition of SECTION active and FORM Active Structural systems

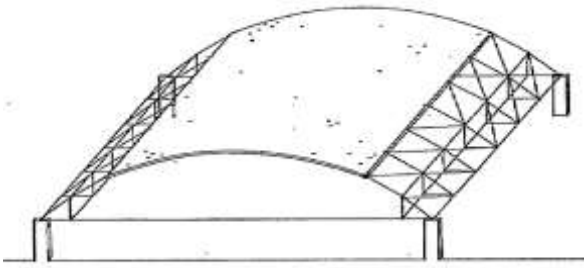


Figure 27 Shell with Truss Segment

Shell with Truss Segment: Coupling of SURFACE active and VECTOR active systems

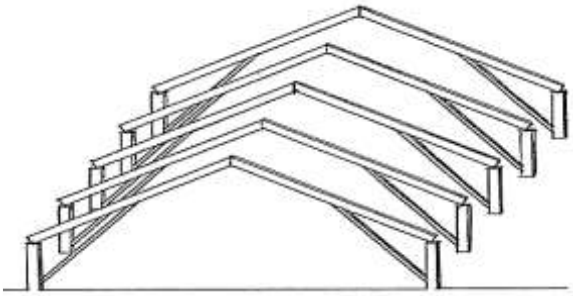


Figure 28 Braced rafter framing

Braced rafter framing: Superposition of SECTION active and VECTOR Active Structural systems

CONCLUSION

- Among the basic requirements that lead to existence, the structure of material forms such as a building, machine, tree, or animate beings is the most important. Material forms can't be retained without structure, and the form object's very destination can't be established without form preservation.
- Geometry, forces, and material characteristics are used to classify basic structural elements. Structures in nature and in technology primarily serve the purpose of preserving physical form, and the form and function of structures are universally valid principles for constructing structure systems.
- In his efforts to change the environment to suit his purposes, man has always looked to nature as a model. Nature exploration gave birth to science and technology. Structure serves as both a natural quality and a support for shape.

Only through their structures will the material forms of the environment retain their identity and so be able to perform their duties. Structures are the natural and technological maintenance of the functions of the material environment

Acknowledgement

This research paper is a part of PhD thesis of Mr. Atul Setya, Research Scholar, Sushant School Art and Architecture, Sushant University, Gurgaon, India

References

Ackermann, K. (. a., 1991. *Building for Industry.* Surrey: Watermark Publications.

Blockley, D., 2009. *The New Penguin Dictionary of Civil Engineering.* London: Penguin.

Boaga, G. & Boni, B., 1965. *The Concrete Architecture of Riccardo Morandi.* London: Alex Tiranti.

Burgess, S. C. & Pasini, D., April 2004. Analysis of the structural efficiency of trees. *Journal of Engineering Design Oxford: Taylor & Francis,* p. pp.177–193.

Chanakya, A., 2009. *Design of Structural Elements.* Oxford: Taylor & Francis.

Coutts, M. P. & Grace, J., 1995. *Wind and Trees,*. Cambridge: Cambridge University Press.

Elliot, C. D., 1992. *Technics and Architecture.* Cambridge: MA: MIT Press.

Engel, H., 1981. *Structure Systems.* New York:: Van Nostrand Reinhold Company.

Fisher, R. E., 1964. *Architectural Engineering—New Structures.* New York: McGraw-Hill, 1964.

Fuller, R. B., 1983. *Inventions: The Patented Works of R. Buckminster Fuller,*. New York: St. Martin's Press.

Greco, C., 2008. *Pier Luigi Nervi.* s.l.:s.n.

Heartney, E., 2009. *Kenneth Snelson: Forces Made Visible, Stockbridge.* s.l.:MA: Hard Press Editions.

Holgate, A., 1986. *The Art in Structural Design.* s.l.:Clarendon Press, Oxford,.

Hunt, T., 1997. *Tony Hunt's Structures Notebook.* Oxford: Oxford Architectural Press.

LeDuff, P. & Jahchan, N., 2001. *Eggshell Dome Discrepant Event.* Oxford: Architectural Press.

Macdonald, A. J., 2001. *Structure & Architecture.* Oxford: Oxford Architectural Press.

Margolis, I., 2002. *Architects + Engineers = Structure.* London: John Wiley & Sons.

Torroja, E., 1958. *Philosophy of Structures.* Berkeley and Los Angeles,: University of California Press.