International Journal of Engineering Research and Technology. ISSN 0974-3154 Volume 10, Number 1 (2017)


# A Comprehensive and Integrated Pedagogical Approach for Teaching Structures in Architecture

**Prof. Shrutee S. Dhanorkar**
*Assistant Professor, Priyadarshini Institute of Architecture and Design Studies, Nagpur, Maharashtra, India. Email id: shrutee20@gmail.com*

**Prof. Aparna Tarar**
*Assistant Professor, Priyadarshini Institute of Architecture and Design Studies, Nagpur, Maharashtra, India. Email id: tararaparna7@gmail.com*

**ABSTRACT:** ***Structure plays an important role in shaping Architecture. The building structure serves two factors namely the technical and the aesthetics. Technical factor takes care of load transfer, impact of forces, stability, etc. and aesthetical factor responds to demand of architectural expression. Structure acts as a skeleton of the body to take up all the loads acting on it to make it stable. The study of structures in architecture includes the understanding of the geometric structural forms, their structural behaviour, and material response and how the forces flow through the built form. It is been observed in architecture students that; there is a perceived separation between design disciplines and structures. The observation indicates that there is a need for new educational model for teaching structures to architecture students.***

***There are various examples in nature which are structurally stable and aesthetically pleasing as stability and beauty comes from nature. The best and supreme creation on nature is Human Body and is familiar to all. Hence human body postures can be used to teach structures to architecture students. The architecture students can be taught by demonstrating various body postures to develop their understanding about the relationship between structural form and forces, structural behaviour and the array of potentially responsive architectural forms.***

***The paper states the pedagogical strategies for structures in architecture education with focus on use of human body postures for simpler teaching learning experience. In larger perspective this paper suggests to develop the pedagogical strategies beneficial for architecture education system here after, which can be referred for using in upcoming teaching learning processes. This helps to nurture the sense of easy, experiential and practical approach in contemporary architecture education system.***

## INTRODUCTION

### OVERVIEW

Structure plays an important role in shaping Architecture. With the change in time Architecture has changed in its functional aspects and its Structure has undergone fantastic technical revolution. The purpose of building is to perform a function. Every Structure is not Architecture but every Architectural output has a Structure. Though the functional and structural components of architecture are most often distinct, structure has always had a decisive influence on architecture. Major facts about structure are; 1. Structure is unavoidable, 2. Structure has to obey laws of nature and cannot always accommodate the desire of the architect, 3. Structure is often hidden and does not appear to contribute to the architecture it supports. [1] Architectural forms often indicate the ways in which loads are transferred. The power and grace of architectural forms stem directly from their structural logic and are inseparable from its form. Structure has always influenced architectural forms of the building.

The teaching of structures within the academic architecture syllabus faces a fundamental problem of difficulty in understanding structures. Architecture students struggle with a traditional

[1] Salvadori, Mario. 1907. *"Why Buildings stand up: the strength of Architecture"*. New York, London: W. W. Norton and Company

engineering based approach to structures, which is increasingly proving to be ineffective in the classroom. There are following observations in architecture students; 1.students struggle to understand formulae and mathematical procedures to solve structural problems, 2.there is inadequate time to teach statically indeterminate structures and other systems that are a bit more complex than simple beams and columns, 3.there is a perceived separation between design disciplines and structures. These observations indicate that there is a need for new educational model for teaching structures to architecture students.

Many different structural systems are used in architecture which are inspired from nature; for example shell structures from egg shell, space frame structures from honey comb, suspended structures from spider web, mud structure from ant hills, folded plate structure from palm leaves, domes from half cut orange peel, bundled tube high ride structures from bamboo, etc. The best and supreme creation on nature is Human Body and is familiar to all. Hence human body postures can be used to teach structures to architecture students as we have accepted the skin and bone concept in architecture put forth by Mies Van Der Rohe.

The architecture students can be taught by demonstrating and experimenting various body postures to develop their understanding about the relationship between structural form and forces, structural behaviour and the array of potentially responsive architectural forms. This paper demonstrates how a curriculum based on experiential body postures (eg. *Yogasana*), haptic learning methodologies and study of live building examples can provide a more effective way forward in educating architecture students about building structures. As initial exposure to complex topics can often make a significant difference in long term learning efficiency, this paper primarily discusses the basics of structures covered in first and second year of architecture education in which students use their bodies to explore basic structural principles related to the relationship between form and forces. There are many pedagogical strategies developed previously by the teachers to teach structures in a simplified manner, few of them were very effective but few techniques did not work for entire class of students.

The paper is concerned with the effective pedagogical strategies for structures in architecture education that lead to better integration of structural systems and human body structure. This also deals with integration of *yogasana* postures for better understanding of human body postures and impact of *yogasana* on learning domains of architecture students. This paper aims at identifying pedagogical strategies to improve the understanding of the structures so that they can implement the knowledge in design studio and integrate principles learned into architectural practice.

The paper states the pedagogical strategies for structures in architecture education with focus on use of human body postures for simpler teaching learning experience. In larger perspective this paper suggests to develop the pedagogical strategies beneficial for architecture education system here after, which can be referred for using in upcoming teaching learning processes. This helps to nurture the sense of easy, experiential and practical approach in contemporary architecture education system.

## ROLE OF STRUCTURE IN ARCHITECTURE

This chapter deals with the definition of structure, various structural systems, technical terms and role of structure in shaping architecture. Examples of various types of structures in nature, skin and skeleton system of structure are also covered in the chapter. As the study progresses the contribution of structure as a subject in architecture education at under graduate level. Efforts have been made to precisely explain the contents.

The literature references quoted in the chapter are mainly from texts that have consciously brought out the symbiotic approach towards teaching structure in architecture. Examples of built forms by Robert Maillart, P. L. Nervi, Santiago Calatrava, etc. have been stated to establish the importance of inspiration from nature and its applicability to architecture.

## DEFINING STRUCTURE

Structure is a fundamental, tangible or intangible notion, construction or framework of identifiable elements (components, entities, factors, members, parts, steps, etc.) which gives form and stability and resists stresses and strains. The basic frame work and skeleton provide for both erection and stability of any structure consist of two portions: 1. Substructure, 2. Superstructure.

## THE RELATIONSHIP OF STRUCTURE TO BUILDING

The simplest way of describing the function of structure is to say that it is the part of a building which resists the loads that are imposed on it. A building structure must be able to support two types of load. 1. Static Load (dead load, live load, settlement load, ground pressure, water pressure, thermal stresses) 2. Dynamic Load (wind load, earthquake load); Static load is assumed to be constant in nature. Dynamic load can be applied to a structure suddenly and vary in magnitude and location. Despite the famous statement by one celebrated commentator, buildings are not machines[2]. Architectural structures must therefore be capable of achieving equilibrium under all directions of load[3].

## STRUCTURAL REQUIREMENTS

To perform the function of supporting a building in response to whatever loads may be applied to it; a structure must possess four properties: 1. It must be capable of achieving a state of **equilibrium**, (this can be achieved when configuration of the structure is such that all applied loads are balanced exactly by reactions generated at its foundation) 2. It must have adequate **strength**, (the requirement of adequate strength is satisfied by ensuring that the levels of stress which occur in the various elements of a structure, when the peak loads are applied, are within the acceptable limits) 3. It must be **geometrically stable**, (geometric stability is the property which preserves the geometry of a structure and allows its elements to act together to resist load) 4. It must have **adequate rigidity** (structural calculations allow the rigidity of structures to be controlled precisely).

A building structure can be said to have at least two aims of equal importance; the technical and the aesthetic. The first aim, the technical function is to stand upright, secure from collapse or excessive deformation. The second aim, the aesthetic function is to act as a potent and meaningful visual vehicle that through the process of refinement can become a convincing and recognizable medium of architectural expression[4] .

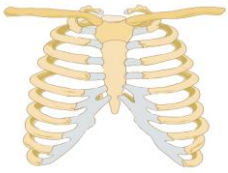
## STRUCTURAL SYSTEMS AND TECHNICAL TERMS

Many different structural systems are used in architecture. The type of system used depends on the building's needs. The height of the building, its load bearing capacity, the soil specifications and the building materials all dictate the proper structural system needed for a building. In particular, structural systems have evolved to focus on building up as undeveloped land has become scarce.

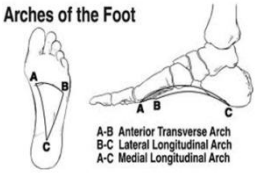
## SRUCTURAL SYSTEM ELEMENTS

BEAM AND COLUMN


FRAME

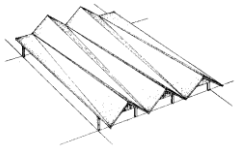



ARCH


[2] Corbusier, Le. (1927). *"Towards a New Architecture",* London, Architectural Press.
[3] Macdonald, Angus J. (2001). *"Structure and Architecture",* Woburn, Reed Educational and Professional Publishing Ltd.
[4] Sandakar, B. N. (1992). "The Structural Basis of Architecture", USA. Whitney library of Design.

WALL AND PLATE




SPHERICAL SHELL AND VAULT


CABLE


## ROLE OF STRUCTURE IN ARCHITECTURE

There is a relationship between structure and architecture, each of these may take more than one form and the type which is in play at any time influences the effect which structure has on architecture. The types of relationships between structure and architecture are:

- Ornamentation of structure
- Structure as ornament
- Structure as architecture
- Structure as form generator
- Structure accepted
- Structure ignored

The structure and the architectural expression co-exist in perfect harmony. Structural form is dictated by structural needs, primarily to support gravity and lateral loads and usually also the need to provide a building envelope for shelter against the elements. The final form which is adopted for a work of architecture is influenced by many factors ranging from the ideological to the severely practical.*"*[5]

## STRUCTURE AS SKELETON

The structure acts as a skeleton of the body to take up all the loads acting on it and make it stable.. On the other hand, the natural forms where flexibility is not a predominant feature, structure itself becomes the form as in an egg shell. We have accepted the skin and bone concept in architecture put forth by Mies Van Der Rohe. He used steel structure as skeleton and glass for enclosure of space just like the skin for the skeleton. The example of skin and skeleton building by Mies Van Der Rohe is Friedrichstrasse Office Building (1921).

Apart from the styles and concepts the following classification of structure specified by Howard in his writings on "Structure-An Architect's Approach", would help clarify the relationship of architecture and structure and be more appropriate in the context of this study: Minimal Structure, Adequate Structure, Formal or Sculptural Structure and Pretentious Structure[6].

## STRUCTURE INSPIRED FROM NATURE

Many different structural systems are used in architecture which are inspired from nature; for example Shell structures from egg shell,

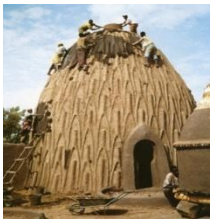

Space frame structures from honey comb,


Suspended structures from spider web,


[5] Salvadori, Mario. 1907. *"Why Buildings stand up: the strength of Architecture"*. New York, London: W. W. Norton and Company

[6] Howard, J. H. (1966). *"Structures: an Architect's Approach"*. McGraw Hill.

Mud structure from ant hills,



Folded plate structure from palm leaves,

## CONTRIBUTION OF STRUCTURE AS A SUBJECT IN ARCHITECTURE

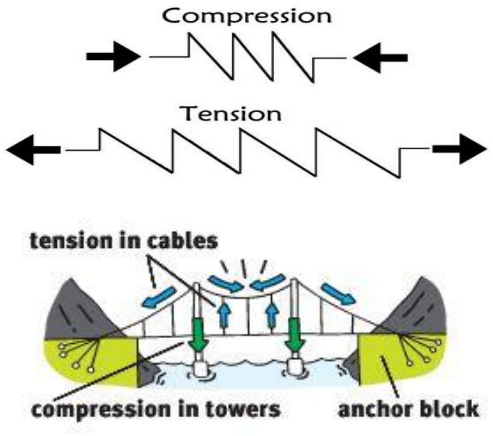
Without doubt, architectural space is intertwined with city image and expresses visual characteristics. A designer should be able to understand structure and its characters in order to utilize them in his design process. Thus 1-forming of an architectural space is simultaneous with its structure 2- semantics and symbolism so that structural form will serve as an underlying format for architectural splendour sought through design.

Understanding structures subject is absolutely essential for the architecture students so that they understand the technical terms related to the buildings they design, they understand the simultaneous action of forces on the building, they understand the centre of gravity for the building to stand erect, they learn the selection of structural system for the design, they learn material selection for the building construction, etc. so that their basics are clear and they can design stable structures.

There are following observations in architecture students; 1.students struggle to understand formulae and mathematical procedures to solve structural problems, 2.there is inadequate time to teach statically indeterminate structures and other systems that are a bit more complex than simple beams and columns, 3.there is a perceived separation between design disciplines and structures. These observations indicate that there is a need for new educational model for teaching structures to architecture students.

## VARIOUS PEDAGOGICAL STATEGIES ADOPTED FOR STRUCTURES IN CURRENT ARCHITECTURE EDUCATION

The teaching of structures within the academic architecture syllabus faces a fundamental problem of difficulty in understanding structures. Architecture students struggle with a traditional engineering based approach to structures, which is increasingly proving to be ineffective in the classroom. Numerous analysts and writers have documented this problem as a national educational weakness and identified it as a threat to the architecture profession. There are following observations in architecture students; 1.students struggle to understand formulae and mathematical procedures to solve structural problems, 2.there is inadequate time to teach statically indeterminate structures and other systems that are a bit more complex than simple beams and columns, 3.there is a perceived separation between design disciplines and structures. Teachers have made attempts for developing innovative teaching methods for structures in architecture education so that the students understand the concepts with ease and generate in the subject. Currently teachers are using graphical representations of the terms and concepts so that the students find it interesting and easy to understand. (Fig. 3.1)



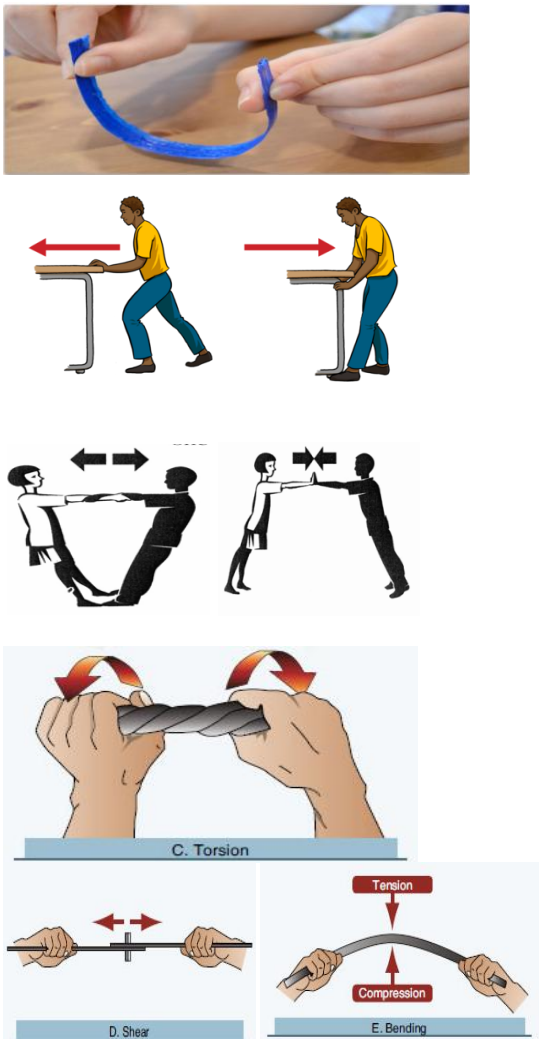



**Fig. Graphical presentations for explaining structural terms and techniques**

## THINK ARCHITECTURE FEEL STRUCTURE

*"To think in architecture, to feel in structure: Teaching Structural Design in the Faculty of Architecture"* is an attempt by Ján Ilkovič, Ľubica Ilkovičová & Robert Špaček from Slovak University of Technology Bratislava, Slovakia. "*To think in architecture, to feel in structure."* The motto is broad and offers freedom of creativity, and encourages exploration, cooperation and discussion in the multi-genre science in which architecture is located.

## PERCEPTION OF STRUCTURE

Structures of many famous architectural masterpieces are inspiring. Perception of structure is connected with a typological kind of a building, its size and function. Perception in this respect can be characterised by one of the feelings, which excite the imagination by their size, dimensions, where the range and height are surprising as are the difficulty of shapes.

## DESIGN ORIENTED APPROACH TO TEACH STRUCTURES

*"Less Is More: A Design-oriented Approach to Teaching Structures in Architecture"*, is an attempt by Michele Chiuini from Department of Architecture, Ball State University. The author states that haunt structures courses in architecture schools:

• Students struggle to understand statics and with applying mathematical procedures to solve structural problems;

• There is inadequate time to teach statically indeterminate structures and other systems that are a bit more complex than simple beams and columns;

• There is a perceived separation between design disciplines and structures courses.

The design studio is normally the focus of architecture students, and structural design is seen as something so different conceptually, that it is left out of their design process altogether.

## PRACTICAL STRUCTURES THROUGH DESIGN BUILD STUDIOS

**Design build studios do not seem appropriate for teaching primary structural principles such as vector analysis, moment or shear diagrams.** Design build studios or competitions do foster significant dialogue between calculation, as a basis for understanding construction problems and the latitude for change in the field. These are all things the practicing professionals and instructors are actually aware but students must get deeply embedded understanding of these issues[7].

## ARCHITECTURAL STRUCTURES – ARCHITECT AS A FORM MAKER

*"Architect as Form-maker: A Fundamental Approach to Architectural Structures",* is an attempt by Dana K. Gulling from Savannah

[7] Phillip Gallegos. (2006). *"Structural Education in Design Build Studios: Questions of Practicality in Student Design Build Projects",* university of Colorado.

College of Art Design. By understanding the fundamentals and integrating them into design, architects can retake the leadership position in the design process. This will establish the architect as the form maker, one who can provide a comprehensive aesthetic solution to a building which still allows consultants to perform the specifics of their tasks[8].

## TEACHING STRUCTURES USING MULTIMEDIA

*"A Comprehensive Approach to Teaching Structures Using Multimedia",* is an attempt made by Shahin Vassigh from University at Buffalo /SUNY. The project findings also point to the great potential of digital technology in other areas of architecture education such as lighting/electrical, plumbing, heating/cooling/ventilation, and construction. Since architects are well trained in digital modelling and providing visualization tools, it is a natural step for architecture education to benefit from this advantage[9].

## DESIGN ASSEMBLE AND DISMANTLE A STRUCTURE

*"Teaching Spatial Structures: Who to Teach, What to Teach and How to Teach",* is an attempt by S. Alireza Behnejad from Space Structures Research Centre, 32AA03, University of Surrey, Guildford, UK. There are also some concerns about the challenges in teaching a group consisting of students from the two disciplines. All in all, it is believed that in teaching a mixed group, more attention should be paid to the basic principles of design rather than the design details.

Design of structures, in general, and spatial structures, in particular, can be considered as an integrated process involving the following main steps:

- Arrangement of the main structural components to satisfy the needs of a structural project referred to as the 'Conceptual Design', which may also be considered as the stage that the key decisions about the project are made,
- Sizing of the structural components based on the modelling, calculations and structural properties of the chosen material, referred to as 'Structural Analysis',
- 'Detailing' of the structure including the design of shape, size and material of the supports, connections and any additional parts to the main structure, and
- 'Practical Considerations' includes the assembly strategy, temporary loading during construction, durability and maintenance.

### DAD (Design, Assemble and Dismantle) Project

The hands-on project was discussed in detail. A more general version of the project also has been organised for secondary school students attending introductory programmes at the University of Surrey. The discussed teaching methods in this paper are aimed to create an interactive learning environment to sustain the knowledge for the students. Although the methods are highly effective, there are some challenges including the time of organisation for each course and safety considerations in practical activities[10].

## SUPPORTING STUDENTS STRUCTURALLY

*"Supporting Students Structurally: Engaging Architectural Students in Structurally Oriented Haptic Learning Exercises",* is an attempt by Rob Whitehead from Iowa State University. In the comments portion of the evaluation for this particular module, students frequently praised the interactive nature of the classroom and oftentimes mention the first laboratory as a positive (and often "fun") first experience[11].

**Hence there is a need for developing new teaching method for structures in architecture**

[8] Dana K. Gulling. (2006). *"Architect as Form-maker: A Fundamental Approach to Architectural Structures",* Savannah College of Art Design

[9] Shahin Vassigh, (2005). *"A Comprehensive Approach to Teaching Structures Using Multimedia",* University at Buffalo /SUNY

[10] S. Alireza Behnejad. (2015). *"Teaching Spatial Structures: Who to Teach, What to Teach and How to Teach",* Space Structures Research Centre, 32AA03, University of Surrey, Guildford, UK.

[11] Rob Whitehead. (2013). *"Supporting Students Structurally: Engaging Architectural Students in Structurally Oriented Haptic Learning Exercises",* Iowa State University.

**education at early stage of the curriculum for clear understanding of the basics of structures. As haptic exercises proved to be the simplest way of teaching structural systems the human body postures can be used to teach basics of the structure in architecture education.**

## STRUCTURAL BEHAVIOR OF HUMAN BODY WITH RESPECT TO POSTURES

The chapter attempts to identify various types of joints in human body which allows certain type of movements of the body parts which helps human beings to form certain postures by stretching, compressing and twisting the body. The best and supreme creation on nature is Human Body and is familiar to all. Hence human body postures can be used to teach structures to architecture students as we have accepted the skin and bone concept in architecture put forth by Mies Van Der Rohe.

Based on the study of previous chapter the importance of haptic exercises shows that there is no simpler way than using the human body postures for teaching basics of structure at the early stage of architecture education. This chapter will review the yogasana as the best medium to understand human body postures and the impact of yogasana on the cognitive, affective and psychomotor domains of learning.

This paper demonstrates how a curriculum based on experiential body postures (eg. Yogasana), haptic learning methodologies and study of live building examples can provide a more effective way forward in educating architecture students about building structures. As initial exposure to complex topics can often make a significant difference in long term learning efficiency, this paper primarily discusses the basics of structures covered in first and second year of architecture education in which students use their bodies to explore basic structural principles related to the relationship between form and forces.

## TYPES OF JOINTS AND POSSIBLE MOVEMENTS OF HUMAN BODY PARTS

The following are the types of joints in human body as per researches in the medical science on human anatomy.

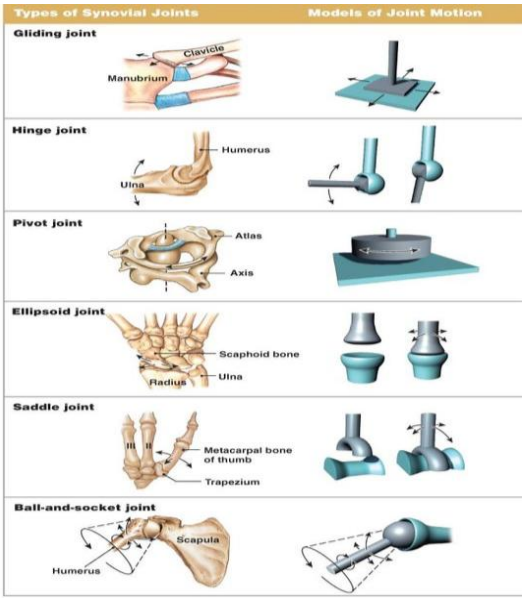



**Table : Types of joints in human body**

Humans have more than 200 bones and joints are the places where the bones meet. In this chapter the types of movements that the joints allow the body to make are shown in the form of images. The study of human body anatomy is restricted to only joints and possible movements to form certain postures. This paper attempts to use body postures for developing pedagogical strategy which uses human body posture to explain the basics of structures to the students of architecture at early stage of curriculum. This is developed for simplified teaching learning process so that the students can actually perform these postures and can learn through self experience. The basic terms related to structure needs to be clear so that the students can understand the complex structures easily as complex structures are nothing but the combination of simple structural systems acting simultaneously to form a complex structural system to derive creative dynamic forms, aesthetical structures, visually unstable yet structurally stable structures which are iconic in nature. The load transfer, the centre of gravity, the structural system is just like the inspiring body posture.

This fact gave rise to a thought to investigate the body postures and co-relate them with the structural terms, identify the forces acting on body during each posture, the simultaneous action of various forces on human body, the tension and compression experienced during performance of the postures. This gave rise to develop stage wise

teaching method for structures in architecture education.

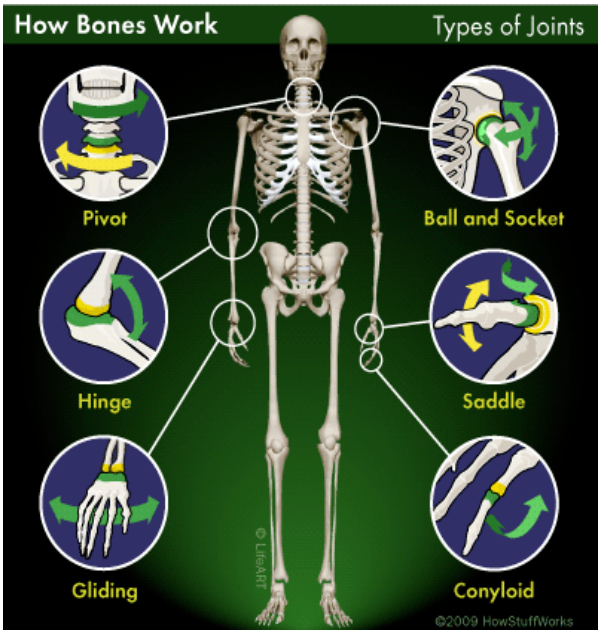



**Fig. 4.1 Human Body Skeleton**

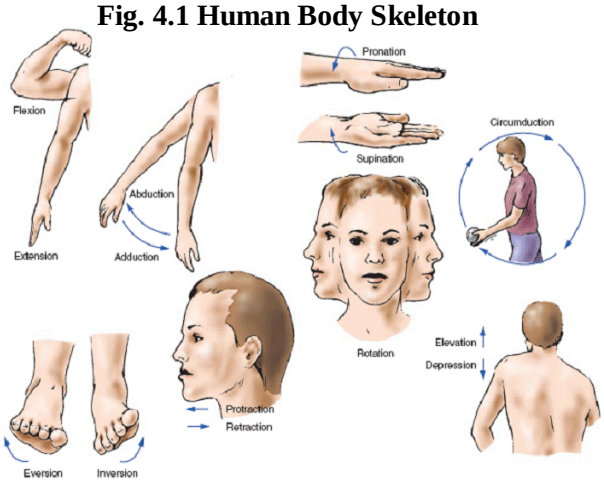
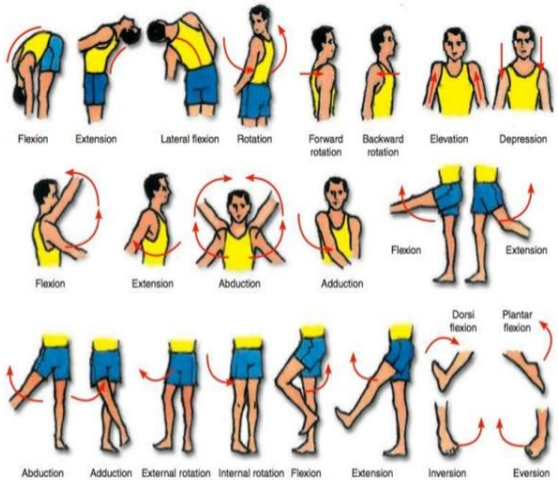



**Fig. Possible movements of human body parts**




## YOGASANA AS THE BEST MEDIUM TO UNDERSTAND HUMAN BODY POSTURES

Yoga is an invaluable gift of ancient Indian tradition. It embodies unity of mind and body; thought and action; restraint and fulfilment; harmony between man and nature and a holistic approach to health and well being. Yoga is not only about the exercise but to discover the sense of oneness with ourselves, the world and nature. Nature has always inspired architecture and human body is the ultimate creation of nature and yogasana is the best medium to understand human body postures. Yoga has eight limbs; Yama, Niyama, Asana, Pranayam, Pratyahar, Dharana, Dhyan and Samadhi amongst which this paper will focus on only "Asana" that is "Yogasana" to understand human body postures.

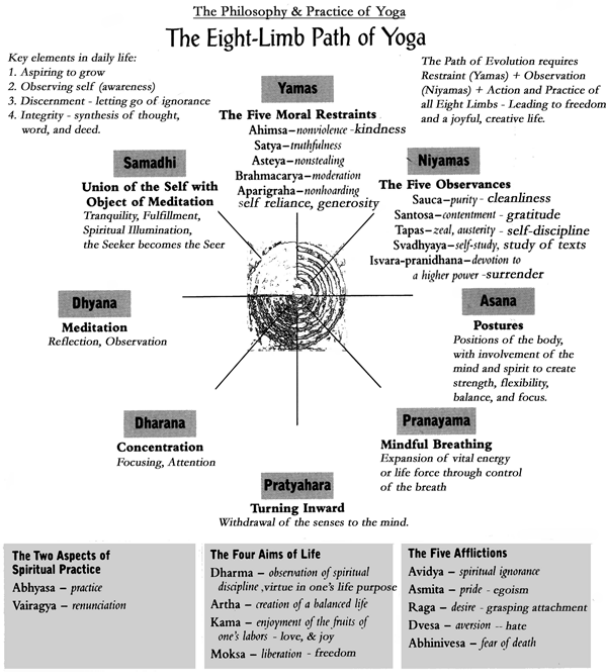



**Fig. Eight Limbs of Yoga**

## IMPACT OF YOGASANA ON DOMAINS OF LEANING

The following tables explain the impact of yogasana on Cognitive, Affective and Psychomotor domains of learning.

| Sanskrit | English | Image | Classification | Benefits (Physical and Mental) | Domains Benefited |
|---|---|---|---|---|---|
| अधोमुखश्वा-नासन | Downward-Facing Dog Pose |  | Arm Balance and Forward Bend. | Strengthens arms, flushes brain with fresh oxygen and calms mind | Psychomotor and Affective |
| बालासन | Child's Pose |  | Kneeling forward bend | Resting pose useful to relieve neck, back and hip strain | Psychomotor |
| वीरभद्रासन I | Warrior I |  | Standing asana (Uttihista Sthiti) | It strengthens muscles of knees and feet, it stretches shoulders and spine, and it improves focus. | Cognitive and Psychomotor |

| Sanskrit | English | Image | Classification | Benefits (Physical and Mental) | Domains Benefited |
|---|---|---|---|---|---|
| उत्तानासन | Standing Forward Bend |  | Standing asana (Uttihista Sthiti) | Relaxes from stress and anxiety | Affective Psychomoto |
| धनुरासन | Bow |  | Backbend (Purva Pratana Sthiti) | Acts as a stress reliever and gives flexibility to the spinal chord | Psychomoto and Affectiv |
| ताडासन | Palm Tree Pose |  | Standing asana (Uttihista Sthiti) | Develops sense of balance, increases concentration. | Affective Psychomoto |

| Sanskrit | English | Image | Classification | Benefits (Physical and Mental) | Domains Benefited |
|---|---|---|---|---|---|
| पश्चिमोत्तानासन | Extension of the posterior (western) part of the body |  | Forward Bend (Paschima Prattana Sthiti) | Strengthens the back muscles | Psychomotor |
| बद्धकोणासन | Bound angle |  | Sitting asana / Forward Bend (Upavista Sthiti / Paschima Pratana Sthiti) | For beginners helps to open up the hips | Psychomotor |
| त्रिकोणासन | Triangle |  | Standing asana (Uttihista Sthiti) | Improves balance and concentration power | Affective and Psychomotor |

| Sanskrit | English | Image | Classification | Benefits (Physical and Mental) | Domains Benefited |
|---|---|---|---|---|---|
| भुजङ्गासन | Cobra Pose |  | Backbend (Purva Pratana Sthiti) | Reduces fatigue and stress | Affective |
| उत्तान पादासन | Raised Legs Pose |  | Backbend (Purva Pratana Sthiti) | Acts as a stress reliever and gives flexibility to the spinal chord | Psychomotor and Affective |
| वृक्षासन | Tree Posture |  | Standing asana (Uttihista Sthiti) | Removes wavering of mind, develops the nervous system and makes it stable, improves concentration | Affective and Cognitive |

**Table Impact of Yogasana on Domains of Learning**

These tables indicate that the selection of yogasana postures for the paper output of pedagogical strategies is done for two major reasons; firstly the yogasana is the best medium to understand the human body postures than any other form of physical exercises like aerobics, dance etc. as yogasana is the origin of all these other forms and secondly yogasana provides mental, physical and spiritual benefits to the practitioner which is good for students in their studies.

**Hence the confluence of building structures and human body postures is done for developing pedagogical strategies for teaching structures in architecture education.**

## CONFLUENCE OF BUILDING STRUCTURES AND HUMAN BODY STRUCTURE (FOR DEVELOPING PEDAGOGICAL STRATEGIES FOR STRUCTURES IN ARCHITECTURE)

This chapter states the final outcome of complete research that is the developed pedagogical strategy of teaching structures stage-wise to the students of architecture at early stage in architecture education curriculum. The stages have been identified as follows:

- Simultaneous impact of various forces on structure
- Types of loads acting on structure
- Centre of gravity
- Stability and equilibrium
- Tension and Compression
- Torsion
- Cantilever, Balanced Cantiliver and Suspended Cantilever
- Replicating Structural Systems using human body postures
- Demonstration of Body Postures like Building Forms
- High Rise Tapering Tower
- Shell Structure Dome

## DEVELOPING PEDAGOGICAL STRATEGIES

The stages have been developed for teaching structures to architecture students at early stage in the architecture education.

### Simultaneous Impact of Various Forces on structure

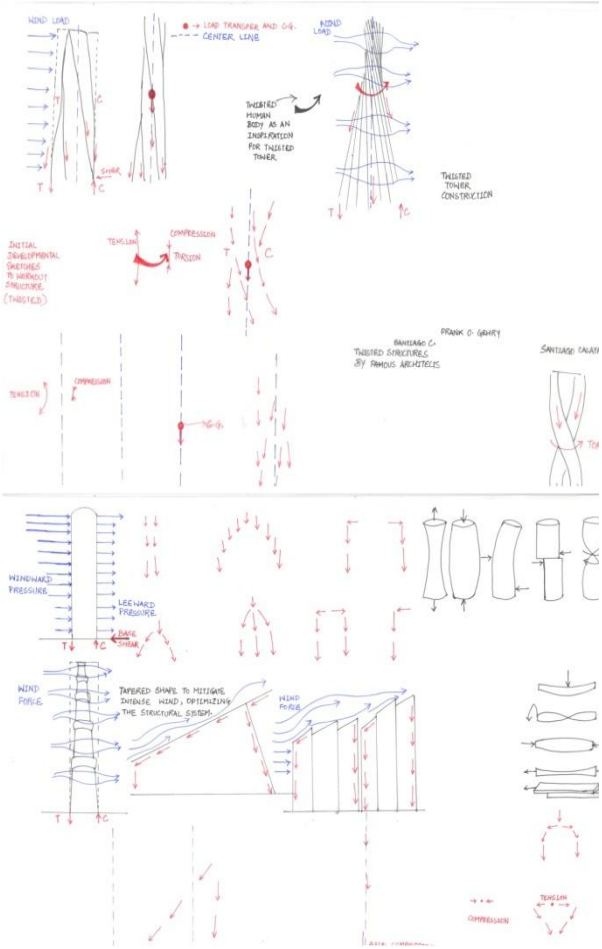
The structure withstands all the forces simultaneously to stand erect. This is how we know why buildings stand up. This is the basic thing to be taught to the architecture students at early stage so that they know why do they need to learn

structures and what do they need to learn to design the structure.

The structure withstands;

- Tension
- Compression
- Shear force
- Bending moment
- Gravitational force
- Wind load
- Seismic forces
- Thermal changes, etc.

The structure reacts to each and every action of forces and maintains its stability by maintaining the centre of gravity. Sometimes the imbalance or poor respond to the applied forces by the structure results in failure of the structure, deflection and even complete destruction of the structure; whereas the perfect structural system with no faults helps the structure or the building or the architectural output to stand. The structure may be visually unstable but it should be structurally stable. This is why we need to learn the structural systems.



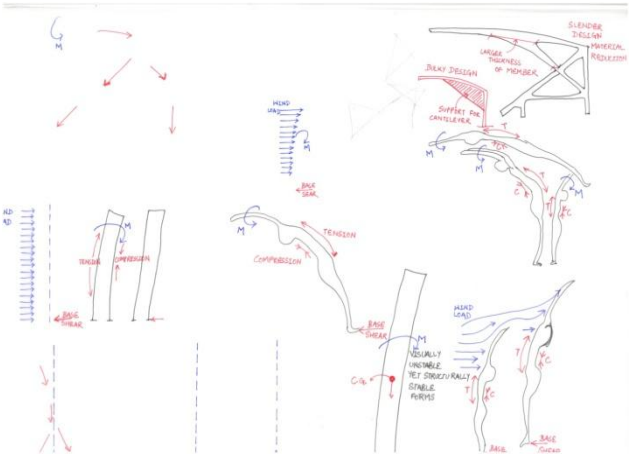


**Fig. Simultaneous Impact of Various Forces**

**Types of Loads on Structure**

There are various types of loads acting on the structure. These are as follows: 1. Static Load (dead load, live load, settlement load, ground pressure, water pressure, thermal stresses) 2. Dynamic Load (wind load, earthquake load); Static load is assumed to be constant in nature. Dynamic load can be applied to a structure suddenly and vary in magnitude and location.

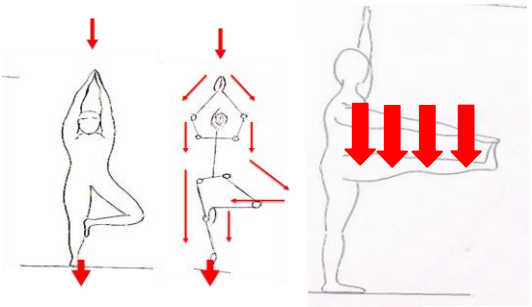


**Fig. Point Load and Uniformly Distributed Load**

**Centre of Gravity**

Centre of Gravity is a point from which the weight of a body or system may be considered to act. In uniform gravity it is the same as the centre of mass. The **Centre of gravity** of a body is that point through which the resultant of the system of parallel forces formed by the weights of all the particles constituting the body passes for all positions of the body.

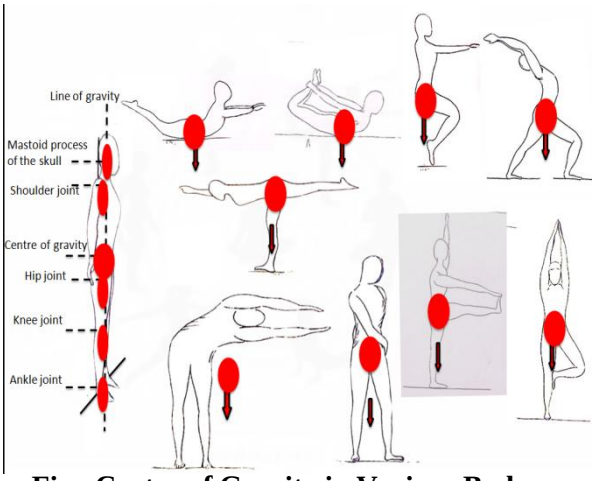



**Fig. Centre of Gravity in Various Body Postures**

**Stability and Equilibrium**

The concept of static equilibrium is usually taught by showing equal and opposite force vector arrows that represent the loads and resistance in a structural system. These arrows are represented only two dimensionally so they do little to help students visualise the challenges of maintaining both translational and rotational equilibrium in a three dimensional system. Students quickly realize that actual structural systems rarely have forces that behave in a straight forward manner suggested by the arrows in the diagrams and they look to alternative methods to visualize structural behaviour.

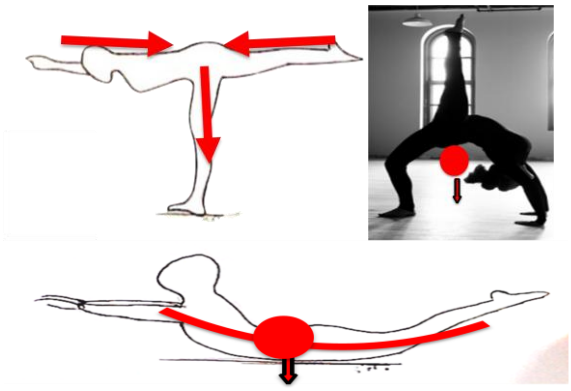


**Fig. Diagrams showing state of stability and equilibrium**

**Tension and Compression**

**Tension and compression** refer to forces that attempt to deform an object. The main difference between **tension and compression** is that **tension** refers to forces that attempt to elongate a body, whereas **compression** refers to forces that attempt to shorten the body.

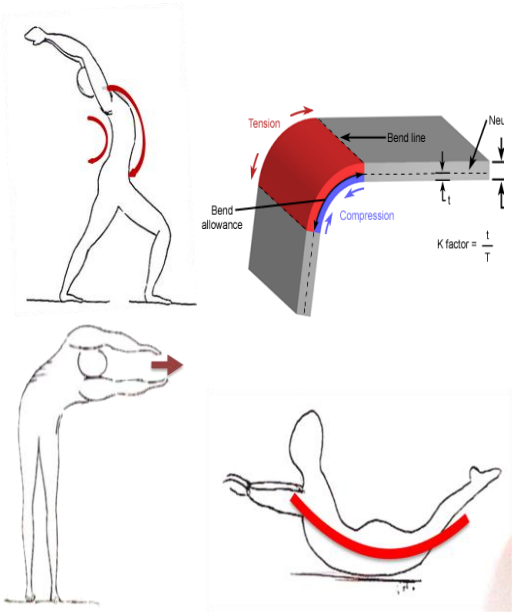
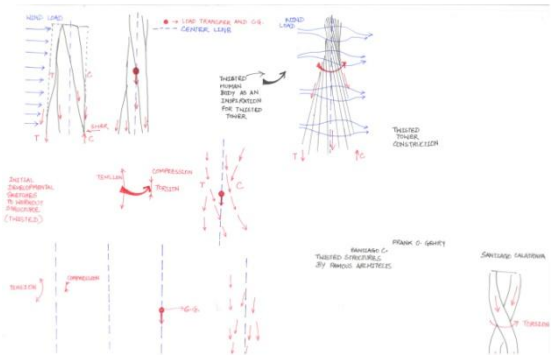



**Fig. Body Postures depicting compression on one side and tension on the other**

**Torsion**

It is the action of twisting or the state of being twisted, especially of one end of an object relative to the other. The stress or deformation caused when one end of an object is twisted in one direction and the other end is held motionless or twisted in the opposite direction.

**Fig. Diagrams explaining torsion**



**Cantilever, Balanced Cantilever and Suspended Cantilever**

Cantilever is a long projecting beam or girder fixed at only one end, used in bridge construction. A cantilever is balanced when the final closure joint connects **cantilevers** from adjacent piers. The structure is hence self-supporting at all stages. The construction may either be cast-in-situ or precast. Suspended cantilever is a projecting beam or member supported at only one end: as a : a bracket-shaped member supporting a balcony or a cornice b : either of the two beams or trusses that project from piers toward each other and that when joined directly or by a **suspended** connecting member form a span of a **cantilever** bridge.

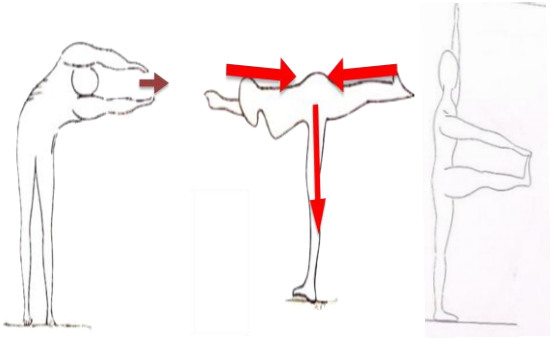
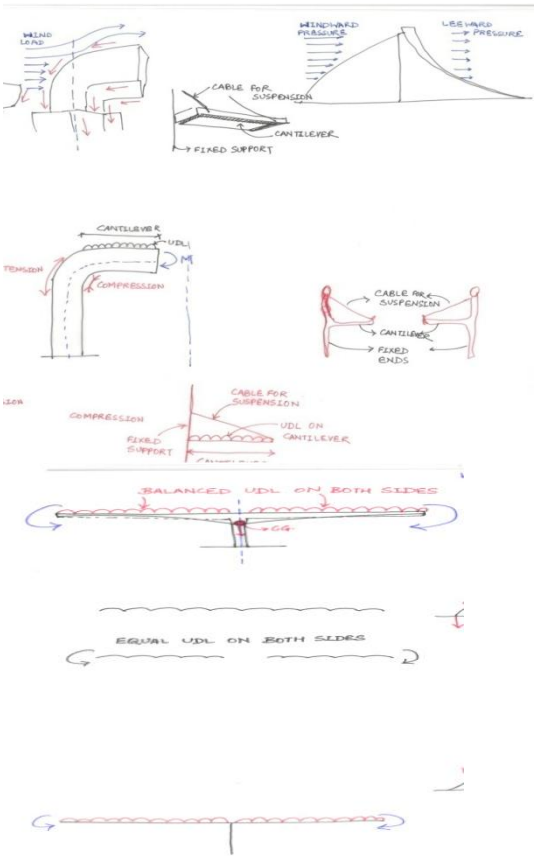


**Fig. Diagrams Depicting Cantilever, Balanced Cantilever and Suspended Cantilever**




**Replicating Structural Systems using Body Postures**

This stage helps students to work in groups and perform the activities and understand the complex structural systems.

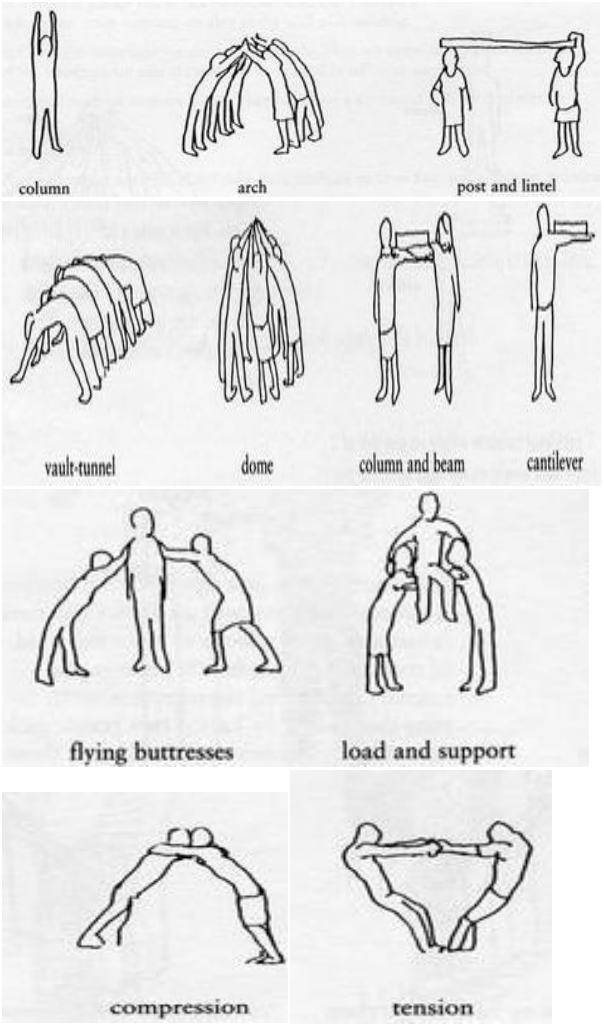



**Fig. Images depicting demonstration of Structural Systems with Human Body**

**Demonstration of Body Postures Like Building Forms**

This activity helps students to understand how structure acts as a form maker and body postures can be used to develop new forms in design. This makes them realize not only the aesthetical similarity but the similarity in structural system and load transfer.

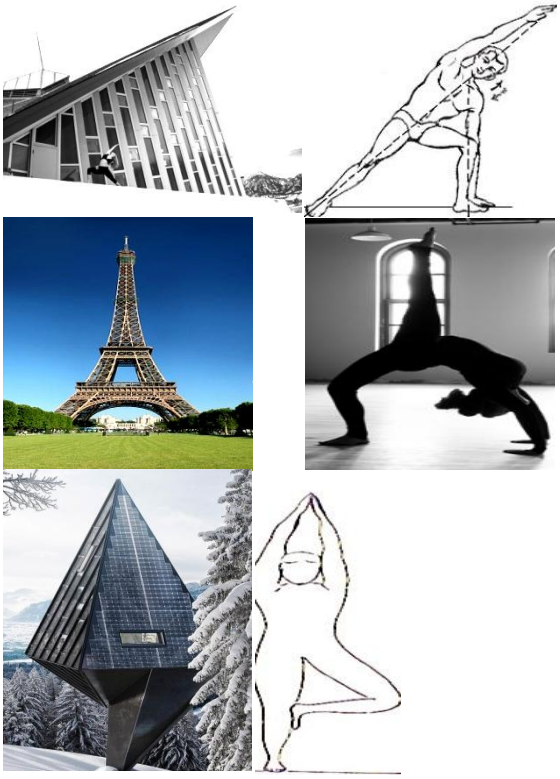


**Fig. Demonstration of Body Postures Like Building Forms**

**High Rise Tapering Tower**

Emporis Standards defines a **high-rise** as "A multi-story **structure** between 35–100 meters tall, or a **building** of unknown height from 12–39 floors." According to the **building** code of Hyderabad, India, a **high-rise building** is one with four floors or more, or 15 to 18 meters or more in height.

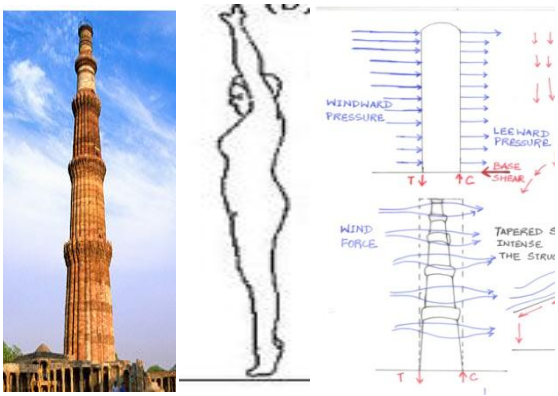



**Fig. Diagrams Depicting High Rise Structure**

**Shell Structure Dome**

The most popular types of thin-shell structures are: Concrete shell structures, often cast as a monolithic dome or stressed ribbon bridge or saddle roof. Lattice shell structures, also called grid shell structures, often in the form of a geodesic dome or a hyperboloid structure.

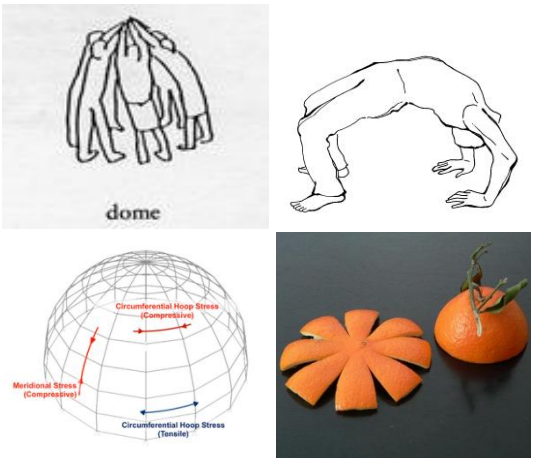



**Fig. Diagrams Depicting Dome Structure**

## CONCLUSION

- Many different structural systems are used in architecture which are inspired from nature; for example shell structures from egg shell, space frame structures from honey comb, suspended structures from spider web, mud structure from ant hills, folded plate structure from palm leaves, domes from half cut orange peel, bundled tube high ride structures from bamboo, etc.

- The architecture students can be taught by demonstrating and experimenting various body postures to develop their understanding about the relationship between structural form and forces, structural behaviour and the array of potentially responsive architectural forms. This paper demonstrates how a curriculum based on experiential body postures (eg. Yogasana), haptic learning methodologies and study of live building examples can provide a more effective way forward in educating architecture students about building structures.

- As initial exposure to complex topics can often make a significant difference in long term learning efficiency, this paper primarily discusses the basics of structures covered in first and second year of architecture education in which students

use their bodies to explore basic structural principles related to the relationship between form and forces.

- The paper states the pedagogical strategies for structures in architecture education with focus on use of human body postures for simpler teaching learning experience.

- In larger perspective this paper suggests to develop the pedagogical strategies beneficial for architecture education system here after, which can be referred for using in upcoming teaching learning processes. This helps to nurture the sense of easy, experiential and practical approach in contemporary architecture education system.

**REFERENCES**


- Salvadori, Mario. 1907. *"Why Buildings stand up: the strength of Architecture"*. New York, London: W. W. Norton and Company

- Corbusier, Le. (1927). *"Towards a New Architecture",* London, Architectural Press.
- Macdonald, Angus J. (2001). *"Structure and Architecture",* Woburn, Reed Educational and Professional Publishing Ltd.
- Sandakar, B. N. (1992). "The Structural Basis of Architecture", USA. Whitney library of Design.
- Salvadori, Mario. 1907. *"Why Buildings stand up: the strength of Architecture"*. New York, London: W. W. Norton and Company
- Howard, J. H. (1966). *"Structures: an Architect's Approach".* McGraw Hill.
- Ján Ilkovič, Ľubica Ilkovičová & Robert Špaček. (2014). *"To think in architecture, to feel in structure: Teaching Structural Design in the Faculty of Architecture"*. Slovak University of Technology Bratislava, Slovakia
- Michele Chiuini. (2006). *"To think in architecture, to feel in structure: Teaching Structural Design in the Faculty of Architecture"*. Department of Architecture, Ball State University
- Phillip Gallegos. (2006). *"Structural Education in Design Build Studios: Questions of Practicality in Student Design Build Projects",* university of Colorado.
- Dana K. Gulling. (2006). *"Architect as Form-maker: A Fundamental Approach to Architectural Structures",* Savannah College of Art Design

- Shahin Vassigh, (2005). *"A Comprehensive Approach to Teaching Structures Using Multimedia",* University at Buffalo /SUNY
- S. Alireza Behnejad. (2015). *"Teaching Spatial Structures: Who to Teach, What to Teach and How to Teach",* Space Structures Research Centre, 32AA03, University of Surrey, Guildford, UK.
- Rob Whitehead. (2013). *"Supporting Students Structurally: Engaging Architectural Students in Structurally Oriented Haptic Learning Exercises",* Iowa State University.