EMERGING ARCHITECTONIC FORMS AND DESIGNED FORMS

Alpana R. Dongre, S.A. Deshpande, and R.K. Ingle

Abstract

Emerging forms are not preconceived. They come into existence through a process and a chain of events that take into consideration the external forces acting on the form and the interaction between individual elements of the composition. Designed forms are a development of an idea or a concept that may be a result of intuition or impression. This research paper deals with exploring a method of conceptualizing a form which is supportive to the structural concepts and is shaped at the hands of a craftsman / designer.

Keywords

Emerging forms, designed forms, intuition, glass box method, symbiotic form.

Introduction

"To be creative, the Architect must be the spiritus rector of all tectonic conditions: use, structure and form; to create his building as an organism – self contained and in its kind – the structural idea must come from him." – Eric Mendelson (1953).

The essence of structural design, a necessity for an architectural form, is to shape the structure to respond effectively to the forces that it must withstand and the human activities it must nurture. Expression of structural action in the form of a structure is one of the direct artistic outlets for a designer. Architectural expression through structural systems, a symbiosis between art and science, is perhaps best illustrated in the bridges of Robert Maillart (1872 - 1940) and the grand stands and hangers by P. L. Nervi (1891 - 1979). According to Nervi's philosophy, function, and in particular load-bearing function, should be the inspiration and driving force in determining the form of a structure. The form may then be designed in accordance with an intuitive feeling for visual aesthetics. According to him, "to search for an economic

solution in the structural field means to find the most natural and spontaneous solution ... to find the method of bringing dead and live loads down to foundations in the most direct way and with minimum use of materials." (Nervi, Pier Luigi, 1965), He believed in the inherent aesthetic force of a good structural solution.
This research paper begins by stating the widely acceptable *black box* and *glass box* approach of design and then suggests a design method that stimulates the emergence of form that could not be preconceived but could be generated by a technique /method. It would aim at the integration of structural concepts, function and architectural expression resulting into a symbiotic form.

The Established Design Approach

Cristopher Jones, (1970) in his book titled '*Design Methods - seeds of human futures'*, mentions the *black box* and the *glass box* approach of the designers. According to design theorists, the most valuable part of the design process is that which goes on inside the designer's mind and partly out of reach of his conscious control. From the creative viewpoint the designer is a black box out of which comes the mysterious creative leap; from the rational viewpoint, the designer is a glass box inside which can be discerned a completely explicable rational process. The creative view of the designer at times becomes incapable of rational explanation. Designers with glass box minds are concerned with externalized thinking and are therefore based on rational rather than on mystical assumptions. One such glass box approach that can stimulate creativity has been put up for consideration.

Study of Emergence of Form

Generally, emergence is defined by saying 'the whole is greater than the sum of the parts'. Resultant structures of the process of emergence are more than the sum of their parts because the emergent order will not arise if the various parts are simply coexisting; the interaction of these parts is central. Emergent structures are patterns not created by a single event or rule. Nothing commands the system to form a pattern. Instead, the interaction of each part with its immediate surroundings causes a complex chain of processes leading to some order. The process of emergence deals with the fundamental question: "how does an entity come into existence?" It is a terminology associated with many natural phenomena, from the physical to the biological domain. For example, the shape of weather phenomena such as hurricanes is emergent structures.

A study of emerging forms in architecture discussed here is one such concept that can help us visualize a form with the functional efficiency along with the structural understanding. Emergence is hard to capture with preconceived model or a theory, just because during an emergence process new and unpredictable entities appear, which are governed by their own laws. It is grooming an idea, a spark, which in the process of emergence comes to transform the inert elements of design into a composition with a life of its own. The idea that excites becomes a concept. The step ahead is a response to the preceding action, every new element has reason for its existence, and the entire form becomes a composition of the support and the supported.

Hanging Models – A Form Finding Technique

Form-finding structural modeling techniques, since historic times, became a basis for exploration in the projects and research involving new forms and new technology. The hanging model functions like a "designing machine", as said by Collins (1971). Hanging chain models are used (in tension) to find compression structures (by inverting the derived form). Antonio Gaudi, the Spanish Architect (1852-1926) had used a similar technique to build up the models of Sagrada Fammila (1882-1926). Inverted models with hanging weights were used to study the profile of compressive forms. Gaudi was a master of his art. Studying the models was one of the approaches he chose to pursue his own research work. Gaudi realized that, in the most general case, the only possible solution was to use space-hanging models (Huerta, 2006). Nervi in the 1930s had made use of models made of celluloid for statistical tests in the laboratory at Milan Technical High School. Since the exact dimensions and calculations could not be worked out with the known methods of structural theory, a scale model was used to obtain the internal forces (Rogers & Jurgen, 1957). This great master approached his designs with a basis of scientific certainty, but transcended it through his intuition.

Intuition is the immediate apprehension by the mind. In the resolution of design, intuition guides us through the inception of the idea to freezing the concept. It tells us when enough options have been explored, sufficient analysis has been done and enough issues involved in the concept have been evaluated. It helps us to draw a line and trust our judgment. Designing through intuition is the 'often quoted' approach of masters; a process or a method that would stimulate creativity and intuitive reasoning however, becomes necessary for the beginners.

The objective of this design method is the conceptual technical approach that coincides with the naturalness and comprehensibility of the entire scheme; the aim being of solving a specific problem in the most efficient manner and with a clear expression of stresses and the materials of which it is built. This approach to design would look into the technical correctness and aesthetic sensitivity as well as will witness a dialogue that would constantly alternate between the two aspects, firstly, the technical and the functional and secondly the artistic.

Methodology

With the intent to explore the bare minimum requirements to build any utilitarian form, a working jig was constructed as a tool which facilitated the form studies. A framework enclosing a cubical volume made up this working jig with anchorages on the frame at different levels. A soft board checkered plane and a weld mesh formed the base and top of the jig respectively. The jig offered anchorages at different levels and different directions in the form of a three dimensional matrix that facilitated in giving a system of proportioning the emerging form. Different working materials with the basic structural properties of compression, tension, bending etc. were identified and the particular designed processed with the basic functional requirements of the activity.

ALPANA R. DONGRE, S. A. DESHPANDE, and R. K. INGLE

Implementation

Process of Emergence

To initiate on a design brief, we need to consciously express the objectives in a preferential order. For the purpose of effective demonstration of the method, the concept development for design of the form of a grand stand, (stadium) is taken into consideration.

The basic requirement of a grandstand is a frame that assists in providing inclined seating with an obstacle free cover above it for unobstructed vision. This single stabilized frame could be repeated to a linear, elliptical, square or circular path to define the boundaries of the play field. The form for inclined seating and a similar roof in the reverse direction was achieved by tying the diagonals of the central plane of the jig (Figure 1). One side of the central axis was to be supported; the other side could emerge as a means of supporting.

The slope of seating tiers in accordance with the requirement of vision, needed to be reduced. It entailed for pulling the members apart at the junction creating a utilitarian space as well as introducing extra supports, the upper pull (the tensile force) and the lower push (the compressive force) (Figure 2).

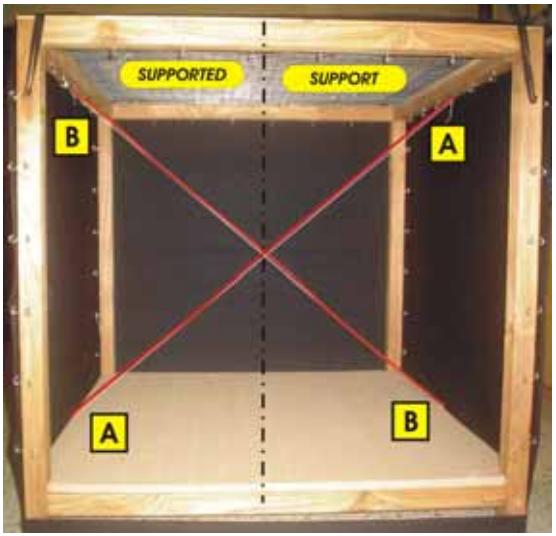

Figure 1:
Diagonals of the central plane A-A and B-B of the jig were tied by the strings to make for the seating tiers and the roof line. One side of the central axis was to be supported, the other side could emerge as a means of supporting.

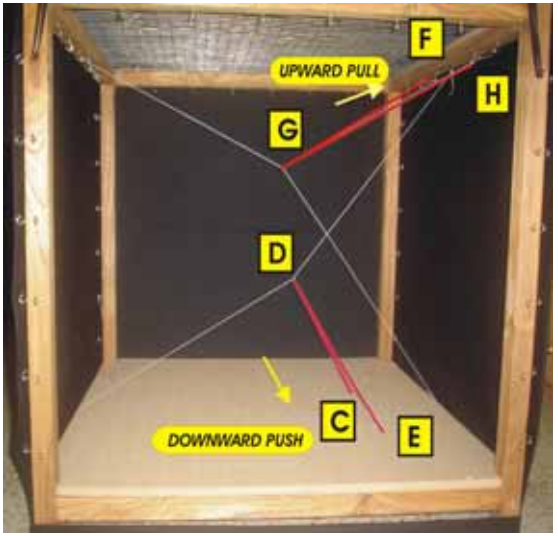

Figure 2:
To reduce the slope of seating tiers the members are pulled apart at the junction creating a utilitarian space. Extra supports, the the downward push CDE (the compressive force) and upward pull FGH (the tensile force) were introduced.

Having satisfied the need of appropriate space, the system had to be now untied from the jig to make the forces flow from the structure directly to the ground. The strings that were pulled and anchored to the jig were to be brought to the ground via additional upright support into the vertical plane, which would facilitate in handling the derived direction of the initial forces and would stand in contrast in compression to the tensile action of the string. A vertical member, forked at one end to take up the two points that lay equally apart from the central axis of the frame was introduced (Figure 3). The forked end was further stabilized by tying the free ends, hence restricting the splitting up of elements and forming an inverted triangular prism, dematerialized to expose the wireframe. In the process of anchoring the points to the ground the forked column was compressed and this inclination under the acting forces took the form of a curve (Figure 4).

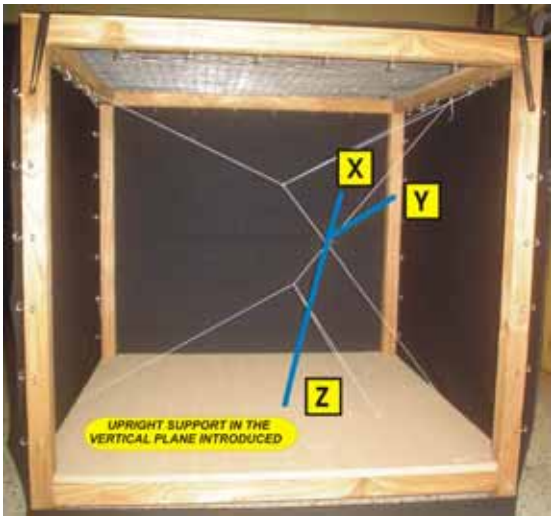

Figure 3:
To untie the system from the jig and let the forces flow from the structure directly to the ground, a vertical member, forked at one end to take up the two points that lay equally apart from the central axis of the frame was introduced.

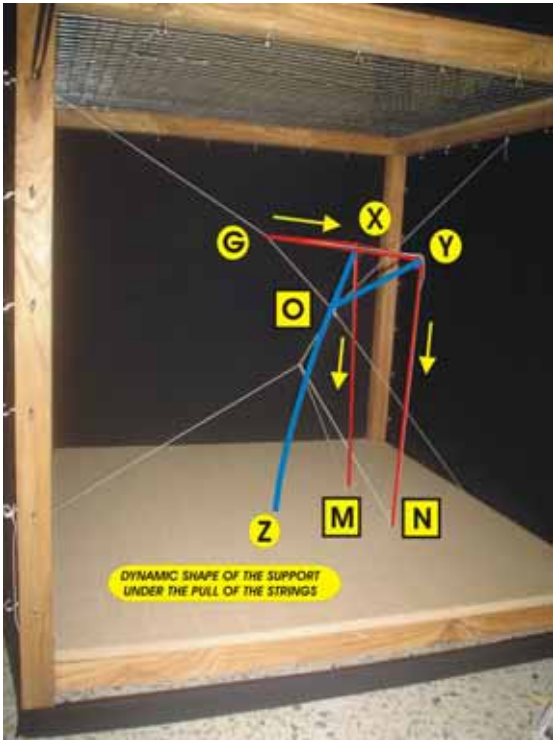

Figure 4 :
To untie the upper pull from the jig and divert forces towards the ground the strings anchoring point G were brought to the ground at M and N through forked ends X and Y. In the process of anchoring the points to the ground the forked column was compressed and this inclination under the acting forces took the form of a curve, the dynamic shape resulting from the action of forces.

The juxtaposition of tensile and compressive forces of the forked support and the stretched strings brought about interplay of forces and their combined effect exhibited a sense of excitement and stability, life and energy.

The roof line over the seating which was until now a simply supported inclined member with both the ends being secured to the working jig and being pulled over the forked column at the mid span, needed to be freed from the working framework that meant it would result into a cantilevered member. An additional bending member was introduced along with the string representing the roof line with an intension to replace the existing form (Figure 5).

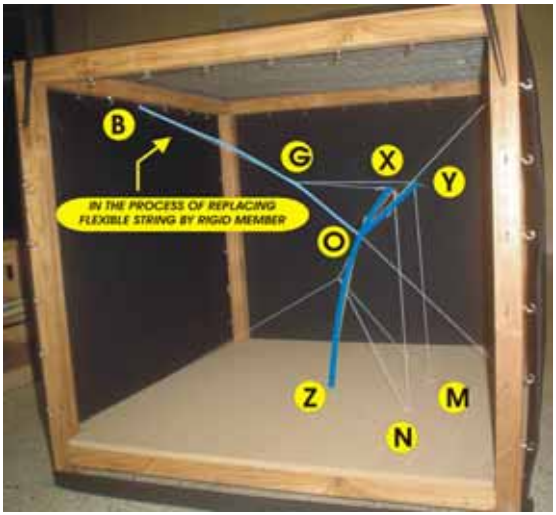

Figure 5 :
The forked end X-Y was further stabilized by tying the free ends, hence restricting the splitting up of elements and forming an inverted triangular prism, dematerialized to expose the wireframe GOXY. An additional bending member BO, to represent the cantilevered roof line was introduced along with the string with an intension to free end B from the jig..

The moment the string was detached from the external frame and a load was added to the free end, depicting the dead load of the member, which was necessary to visualize the bending form of a cantilever, the entire system collapsed (Figure 6).

The reasons for the collapse were studied. There was no proper anchorage at the junction of the forked column and the base of the cantilever and hence the unsupported span of the projection outstretched more in limits to the rigidity that was provided by the supported length. This directed the further step into fastening the supported end of the cantilever by making it a part of the defined geometry of the inverted pyramid and increasing the rigidity of the joint. (Figure 7) This helped in safely unfastening the member from the temporary working supports with an added observation of the rotational effect of the cantilever, as if the cantilever was acted upon by torsional forces about the pivot at the junction (Figure 8). This could be stabilized by a counter force in a single frame or by the lateral ties in the multiple frames repeated to make up the grand stand.

This was the glass box approach of conceptualizing a model for understanding the forces and stability requirements for a given function. With the emerged form standing in absolute equilibrium, the method has led us to the visualization of nature of stresses, interplay of forces and to some extent choice of material properties. The stretching of strings, the application of loads, the anchorages at joints were guided by the power of intuition, the aesthetic judgment and the capacity of the form and material to resist the applied loads. At all stages the decision was frozen at a critical point beyond which the assembly would not confirm to the principles of stability.

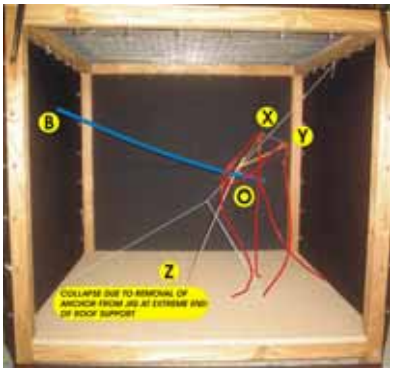

Figure 6:
The moment the string was detached from the external frame at the anchor B and a load was added to the free end, depicting the dead load of the member, which was necessary to visualize the bending form of a cantilever, the entire system collapsed

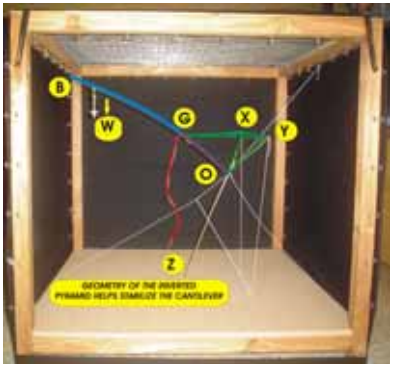

Figure 7:
The supported end of the cantilever was fastened by making it a part of the defined geometry of the inverted pyramid and increasing the rigidity of the joint. The anchor at B could now be unfastened safely.

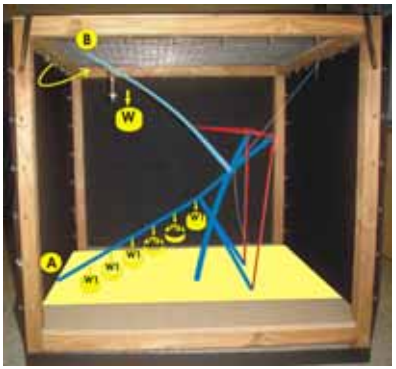

Figure 8:
With the unfastening of the free end B , of the cantilever, a rotational effect bout the pivot at O was observed, as if the cantilever was acted upon by torsional forces about the pivot at the junction. This could be stabilized by a counter force in a single frame or by the lateral ties in the multiple frames repeated to make up the grand stand. Member AO would also act as a bending member under the live and dead load of the seating depicted conceptually by W in the figure.

Emerged Form to Designed Form

Let the form emerge, emerging forms are not preconceived. Through the process of design development and refinement, they tend to culminate into designed architectonic expressive forms. The process documented above is the technique / method of understanding and conceptualizing a form. It is a tool for communicating the design idea. The first step in design – commonly termed as 'search for a form' or search for a suitable structural solution has been accomplished. An architectonic form needs to be given to the basic emerged form. The essential lines of this wire frame model and the movement of stresses of the emerged model are not recognizable as architectural forms, they need a transformation into elements of a composition with utility that is build able and constructible. Superimposition of the designed architectural form with the authentic expression of material would always keep us near to the emerged form. The elegance and consistency of a solution always stems from the authentic use of any material. For example, reinforced concrete is truly explored in all forms that are absolute expressions of plasticity. The superimposed form becomes the container of these stresses and speaks for the behavior of the designed form.

The designed form ought to express the tectonic and visual quality inherent in the emerged form. The seed of the feeling which the designer seeks to express has already been planted, the work has now to be approached in the spirit of a craftsman, applying some body of technique which tells him what he must do to uphold and highlight that particular feeling. The statics of form has succeeded in creating the impression of stability and safety. The Roman theorist, Vitruvius, (c 90 -c20 BC), in one of his oldest treatise in architecture has prescribed three attributes that architecture should have: Utilitas (appropriateness, practicality), Firmitas (stability, solidity) and Venustas (grace, beauty). Utility and function are the basis of any architectural design; structure is implicitly included under Firmitas. The term Venustas expressed delight. Security is the primary element that generates the feeling of delight. We say the structure has emerged when each element is performing the task of holding or supporting, support and the supported. Upholding the same concept, Ruskin (1857) in his Seven Lamps of Architecture, uses the logic of 'fallacy' to highlight the spirit of the Lamp of Truth, categorizing Structural Deceits as the suggestion of a mode of support other than the true one (Deshpande, S. A., 2006).

Techniques of transforming the wire frame into architectonic form

With the intent of transforming the wire frame model of stretched and compressed members into architectural form, the material of construction, the appropriateness of the bulk, the possibilities of dematerialization and dealing with critical points of design should be favorably handled. The techniques that can help us design a form over the emerged form are briefly referred to in the text to follow along with some evolved design concepts.

Technique 1: All works of art need a material support. Material is more in design, than merely a support. It is not an added quality, but an essential part of it. The fusion of material and form is the absolute aim of all great art. The agreement between material and form needs to be made as intimate and thorough as possible so that the work may achieve

resemblance with the living organisms in nature, in which it is impossible to dissociate force from form. Every material will react differently under the forces of compression, tension, or torsion and will assume its own forms of resistance. These particular forms are for each material an integrated part of the design language of the material. The worse mistakes in design happen by using a material in forms that belong to another material.

Reinforced concrete is a material which is formed by the combination of two materials: steel and concrete. One cannot see inside a reinforced concrete section to observe how the steel is placed or how it is functioning: it is hidden. The means by which the cross-section can carry or transmit its load is only obvious if the cross-section is working in compression. The clues as to how the structure and its components function are given in the shape of the cross-section of the elements and in the form of the structural system.

What is the essential quality of steel as a building material? As a building material, steel appears first and foremost as linear units pieced together to form frames trusses and space frames. The combination has two tasks: to provide space for functions and to give form to a character. Steel is articulated and assembled while concrete is monolithic and rigid. The material properties suggest that steel cables and ties can resist greater tensile stresses that can lead to slenderness in the entire composition as the forces can stay within a small cross-section. With the advancement in material sciences, many new materials of remarkable strength, lightness and workability are available. Selection of material on the basis of stress carrying capacity is of utmost importance.

Technique 2: The Bending Moment diagram is the analytical step in the design process, the **interpretation of BM/SF diagram** in architectural form is the architectonic expression of the structural forces. The reduction in stresses and moments can be expressed either by narrowing the cross-section or by dematerialization of the element into an open web form. The points of zero moments can be hinged joints. Thus, the form of a reinforced concrete structure is its singular expression of the magnitude of loading and therefore of its function. P.L. Nervi, in his design of Stadium at Rome has used the characteristic shape of the Moment diagram at the cross section of the cantilever that clearly expresses the concentration of forces in the structure (Figure 9). The fusion of structural considerations with a formal solution is complete.

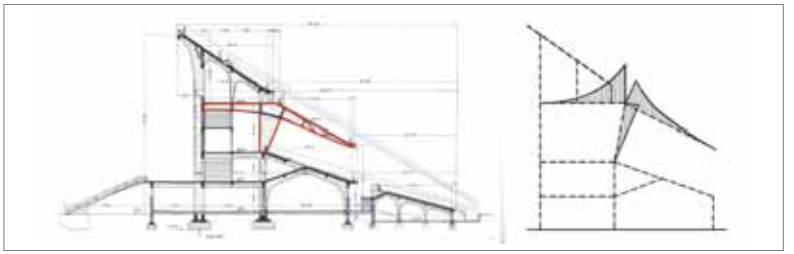

Figure 9:
Grand stand of stadium in Rome, P.L.Nervi, 1935. (Rogers & Jurgen, 1957)

Structurally and aesthetically interesting is the freely cantilevered middle tier.
The resemblence in the bulk of material and the moment diagram is very precise.

Technique 3: The joint or major **nodes are points of convergence of multiple forces**. They act as skeleton joints in the human body and need to be supported by the ligaments and muscles to allow for their functional movement. The expression is carried forward by a bulk of material at such joints. Antonio Gaudi in his life time creation of Sagrada Famillia Cathedral (1882 - 1926) has related the similar principle by providing for knots as in the arboreal system of branching supports in the columns of the nave and the aisle (Figure 10). Transition from a star shape to a circle is hidden within the knot.

Figure 10 :
The knot that Gaudi has used to depict the concentration of forces. He quotes, 'Nature is my master' (Armengol, 2000) These knots marked the various elements of transfer between columns or of continuity between trunk and branches, of concentration of stresses in accordance with the image of the wood and the trees.

These knots marked the various elements of transfer between columns or of continuity between trunk and branches, of concentration of stresses in accordance with the image of the wood and the trees. The knot that Gaudi suggested was a response to the multiple forces at the junction, in the form of architectural expression. Increasing the cross-section at joints is the direct expression of convergence of multiple forces.

Technique 4: Behavior of different forms and the **insight into transformation of forms** also contribute to evaluating various design options. For example, the funicular shape of a cable when placed upside down becomes an arch. Adding a tie between the two supporting ends of a cable fulfills the principle of triangulation and hence behaves like a truss. A bow string truss can be transformed into an arch by removing the tie and adding buttresses for lateral supports. In the conceptual design sketches included herewith options like arch with a uniformly distributed load, a portal or an inclined beam are alternatives to support the inclined seating.

The emerged form has been superimposed by designed forms shown as various options in figures 11, 12 and 13. The comprehension of the nature of stresses and the conscious use of the above mentioned tools has helped in shaping the structure to generate various design alternatives. The logical result of the method at a conceptual stage has been illustrated in Figure 14.

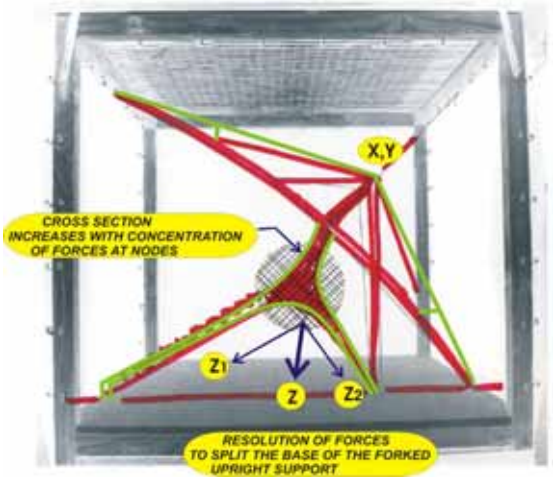

Figure 11:
The emerged form being overlapped by the designed form. The basic principles of statics (resolution of forces) and the techniques suggested in the text being used to shape the architectonic form.

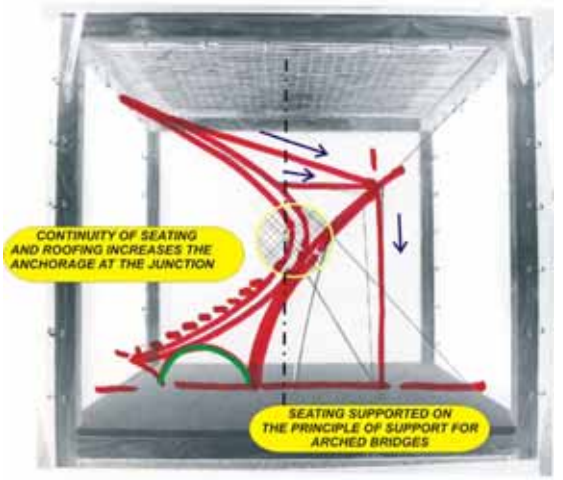

Figure 12:
The continuity between the roof and the seating tiers balances the curved support in the opposite direction. The assembly is supported on the the arches at the lower end taking due benefit of negative bending moments beyond the arch.

Figure 13:
Alternatives of different designed forms on same emerged form. Transformation of structural shapes, variation in material, response to the nature of stresses, can lend varied expressions to designed forms.

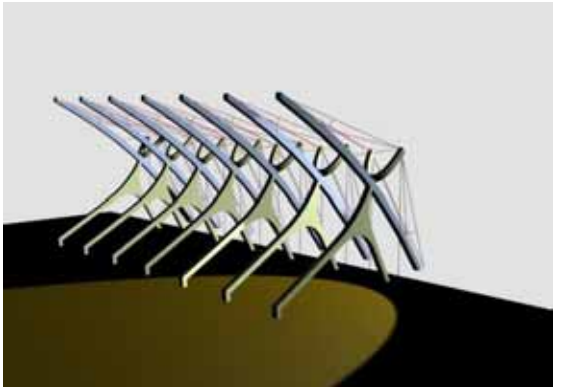

Figure 14:
A logical form developed establishing the structural aesthetic sensitivity of the process at the conceptual stage. Calculations and design refinement will follow.

Application

This method works out to be a means of understanding and visualizing the basic structural forces, especially at the initial stages of design and conception for special buildings. The tautness of the strings, the compression of the uprights, the rotation of the free end and the impact of the eccentricity can be perceived and experienced. The mindful concern for aesthetics, the dynamism of form, the aptness of geometry and proportions is nurtured with the modular working framework. It is an interdisciplinary approach that bridges the gap between the art and engineering of construction and sets up a communication link between both the disciplines. The solution to a particular set of requirements emerges as a model in sequential progression leading to the structural form or an initial statement of the erection possibilities. Of course the end solution is not as simple as that but it could work well as a communication tool at that stage of design.

Limitations

The working material used for visualizing the model through the process of emergence has not been specified here. The other quantifiable attributes of the form are not taken into account. Understanding the nature of stresses is of greater relevance to determine the form. It is the exercise based on the basic elements of load transfer, the arch, the cable and the beam and the basic forces of compression, tension and bending. Similar concept can be worked out for planer and other three dimensional forms.

Conclusion

Plastic form uncontrolled by structure rings a hollow note. Technology has made plastic form easily possible for us. But it is the esthetic reason which is a driving force behind its use. The way in which the form has emerged, emphasizes the paramount importance of the method for providing the stimulus necessary for innovation and generation of a symbiotic form. The principal motivating philosophy is the drive towards 'correctness' in building directing us towards the integration of art and engineering in the built form. The method establishes the fact that though the individual force is static, the play and interplay of forces is always dynamic. It is our task to find an architectonic expression for these forces of mobility, and by means of architectonic form to establish equipoise for these tensions, as well as to master the inner forces which are bent upon expressing themselves in outer forms. It is the tectonic principles of architectural composition that leads us to the experience of sublime beauty.

References

Armengol, J. B. I. (2000). 'The Essential Gaudi,' ECSA, Barcelona, Spain.

Collins, G.R. (1971). 'Antonio Gaudi and the Uses of Technology in Modern Architecture,' In Proceedings of the First National Conference, Civil Engineering: History, Heritage and the Humanities. Vol. 1, Princeton University Press, Princeton, New Jersey, USA.

Deshpande, S. A. (2006). 'Rekindling the Lamps of Architecture,' Architecture + Design.

Huerta, S. (2006). 'Structural Design in the Works of Gaudi,' Architectural Science Review. Vol. 49 (4), University of Sydney, Sydney, Australia.

Jones, Ch. J. (1970). Design Methods: Seeds of Human Futures, John Wiley & Sons, New York, USA.

Mendelson, E. (1953). 'Foreword,' In L. Michael (ed.), Contemporary Structures in Architecture, Reinhold Publishing Corporation, New York, USA.

Nervi, P. L. (1965). Aesthetics and Technology in Building: The Charles Eliot Norton Lectures, Harvard University Press, Boston, Mass., USA.

Rogers, E. N. & Jurgen, J. (1957). The Works of Pier Luigi Nervi, The Architectural Press, London, UK.

Ruskin, J. (1857). The Seven Lamps of Architecture, Wiley & Halsted.