공간구조의 발전 동향

Developments of Spatial Structures


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1. Introduction

In a mathematical definition, space is a set of elements or points satisfying specified geometric postulates, but also it is the infinite extension of the three-dimensional region in which all matter exists. From this terminology, it is considered that a spatial structure is the one that can cover a long-span space with a light weight structure. The shape of structures such as thin concrete shells, grid-shells with steel structure or cable structures including membranes varies from regular geometries with intrinsic symmetries to free structures, covering a wide range of architectural and structural possibilities. The structural behavior and other physical performance related to acoustics, energy, light control, weight, etc. are all strictly depending on the shape of the structure, both at the global and local levels. For this reason, the structural design takes a greater importance rather than the architectural design, and very specific and technical knowledge is needed in order to perform a good optimization of the structure. A finite number of parameters must be defined to represent the global shape, paying attention to the fact that when a few parameters are used, only a small subset of solutions is considered, while with many parameters, the process becomes very complex and time consuming.

A multi-objective oriented design has the purpose of investigating shells' structural optimization as a starting point to more complex problems. Optimization and searching algorithms in combination with various analysis procedures have been used to generate shell structures that are especially capable of

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responding to structural, constructional and acoustical demands. These methods serve virtually the same purpose.[1]

In the case of simulation software, the input they need is too elaborate from the concept design stage. It means that for projects with high technical requirements and economic and time constraints, the designer is forced to consider only a few alternatives to shorten the early design phase and to make the best of it in later stages (traditional optimization process). In the case of optimization algorithms the problem with them lies in the manner in which they have been traditionally used, the way they are formulated, and the focus given to them. Traditionally, optimization algorithms are left for the final stages, when the technical issues of the project are usually taken into account. However, in the final stages of design, many decisions in many different fields have already been made so that changes in the project could easily conflict with previous decisions. Then, the search space of this optimization algorithm is very small and that limits the possibility of innovation. For all of that, the creation of tools and design criteria that can introduce optimal solutions to diverse and perhaps contrasting technical issues in the early design phase without hindering creativity should be proposed.[1]

In this article, various spatial structures that have been historically developed during the aforementioned processes are introduced, focusing on three types of structural systems: form-active, vector-active, and surface-active structural systems.

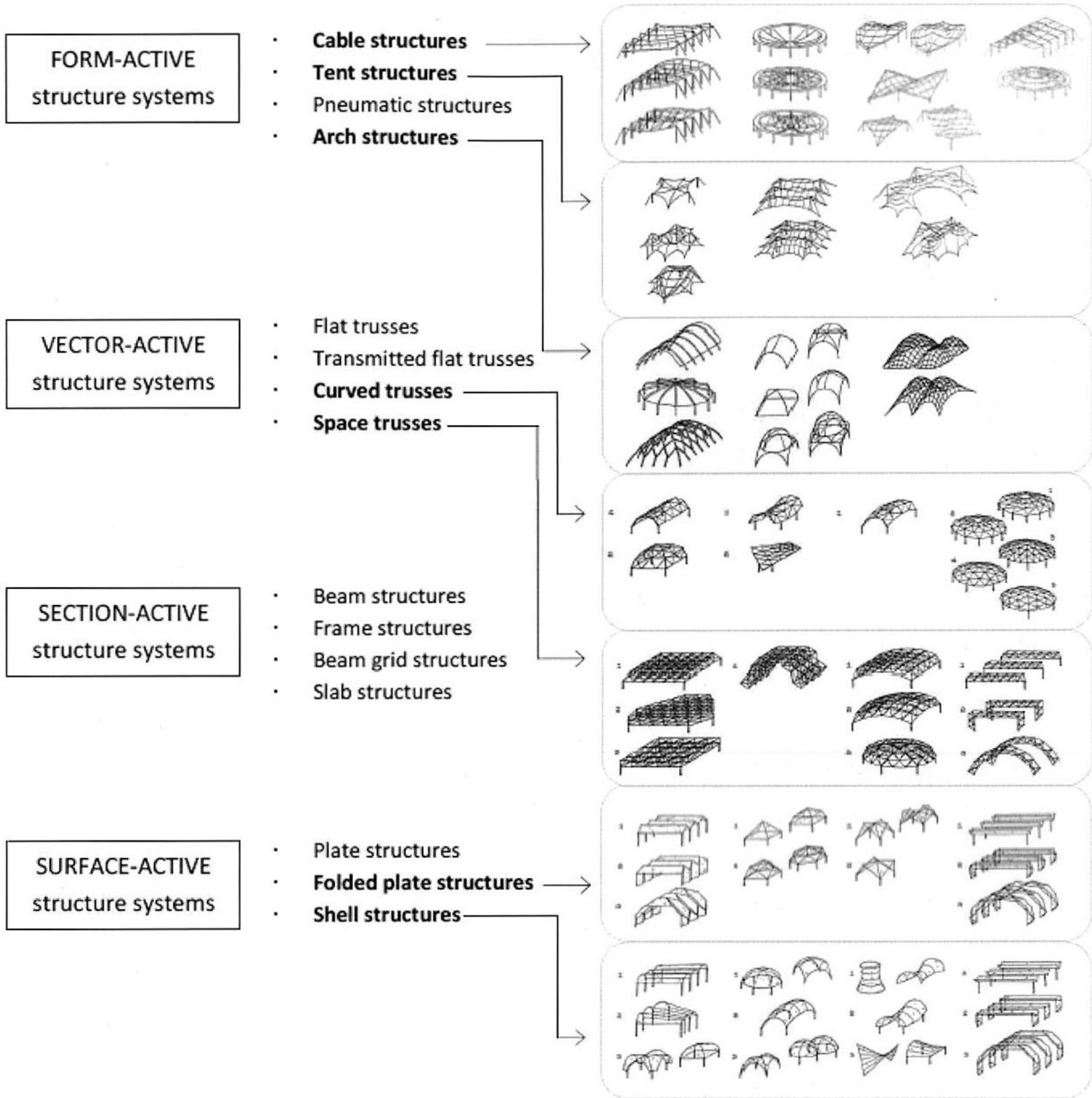
2. Various Spatial Structures

Three main types of spatial structures are categorized depending of the different structural systems they use (Fig. 1). Here, section-active structural systems such as frame structures are not included. In the case of form-active structural systems, structures such as cable, tent or membrane, and arch structures have a single stress condition composed by compressive or tensile forces; the forces are acting mainly through the material form. On vector-active structural systems, structures like curved or space trusses can be found where both compressive and tensile forces act through the composition of the members. Finally, on the surface-active structure systems, the forces are acting through the extension and form of the surface, like it happens in folded plate or shell structures.

2.1 Form-Active Structural Systems

Form-active structural systems, because of their dependence on loading conditions, are strictly governed by the discipline of the 'natural' flow of forces and hence cannot become subject to arbitrary free form design. Architectural form and space should be the result of the bearing mechanism.

Prestressing systems can eliminate those demerits of form-active structures. A suspension cable can be stabilized by prestressing so that it can receive additional forces that also may be upward directed. In the case of arch, they can be precompressed to a



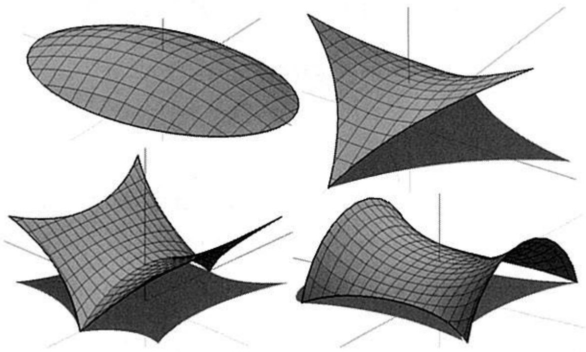
〈Fig. 1〉 Spatial structures classification (reinterpreted from Heino Engel[2])

degree that it can redirect asymmetrical loading without critical bending.

Because of their identity with the ‘natural’ flow of forces, the form-active structure systems are the suitable mechanisms for achieving long spans and forming large spaces. The form-active structural systems (Fig. 2) disperse loads in the direction of resultant forces. In cable nets, membranes or lattice domes, the loads are dispersed in more than one axis, still being transferred in a linear way because of lack of shear mechanism.[2]

The power of tensile structures is that while under compression a thin structural member will escape the direct force line by buckling sideways, whereas under tension there is only one way, the straightway. High strength materials can be used and make members thin.

Their stability is generated by having two intersecting force surfaces stressed against each other.

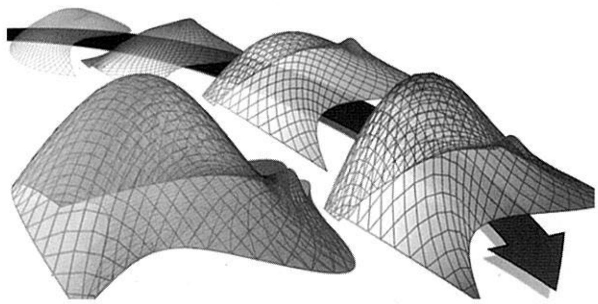


〈Fig. 2〉 Tensile and pneumatic structure[3]

2.2 Vector-Active Structural Systems

Compressive and tensile members in triangular assemblage form a stable composition complete in itself. That, if suitably supported, receives asymmetrical and changing loads and transfers them to the ends. Those compressive and tensile members, arranged in a certain pattern and put together in a system with hinged joints, form mechanisms that can redirect forces and can transmit loads over long distances without intermediate supports (Fig. 3). Distinction of vector-active structural systems is the triangulated assemblage of straight-line members: triangulation. The position of truss members in relation to the external stress direction determines the magnitude of vector stresses in the members.

Redirection of forces through vector mechanism does not necessarily occur in a plane, nor in an axis. Fissure of forces can be also accomplished both in curved planes or three-dimensional directions. By arranging the members in single or doubly curved planes the advantage of form-active redirection of forces is integrated and thus a cohesive load-carrying and stress-resisting mechanism is set up: curved truss system. Knowledge of the space geometry, the systematic identification of polyhedral and the laws of spherical trigonometry is a prerequisite for utilizing the multiple design possibilities of space trusses.



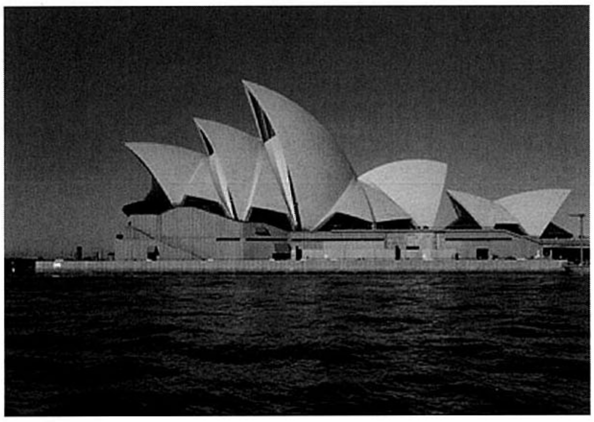
〈Fig. 3〉 Optimization form & grid gridshell[4]

The mechanism of vector-active redirection of forces can be applied also to other structural systems, especially if these, because of dead weight increase, have reached the limits of feasibility. Thus arches, frames, or shells can also be designed as trussed systems.

2.3 Surface-active Structural Systems

Surfaces, finite and fixed in their form, are instrument and criterion in space definition. They are the most effective and most intelligible geometric means of defining space. If given certain qualities, they can perform load-bearing functions: structural surfaces. Without additional help they can rise clearly while carrying loads. Structural continuity of the elements in two axes, i.e., surface resistance against compressive, tensile and shear stresses, are the first pre-requisite and first distinction of surface-active structures.

In horizontal structural surfaces the bearing capacity under gravitational load decreases with increasing surface (slab mechanism); however, in vertical structural surfaces the bearing capacity increases together with the surface expansion (plate mechanism). By inclining the surface toward the direction of the acting force or by folding or curving, it is possible to create horizontal long span and at the same time achieve vertical efficiency in resisting gravity loads.



⟨Fig. 4⟩ Surface-active structure: Sydney Opera House

3. Concluding Remarks

This article introduced three main types of spatial structures, that is, form-active, vector-active and surface-active structural systems, and discussed their mechanisms and advantages. For further developments of such spatial structures, creation of powerful computer tools and design criteria is needed that allows for optimal solutions in both the early and final design phases. It should be ensured at the same time that the developed design criteria and analytical technologies are to enhance the efficiency of the architectural and structural design, not to hinder architectural creativity.

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