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ARTICLE

Transformable Geometries of Architecture between the Years of 1950 and 2015

Mª Dolores Álvarez Elipe*

CEIPSO Salvador Dalí, Spain

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ABSTRACT

During 50 and 60 years, architecture began to experiment new processes of adaptation defining new deployable typologies in the engineering and architecture that had not been experienced until that moment. Transformable forms were developed from the study of geometry. Since then it has been emerged studies of this type by researchers who have continued or have been interested in these works. Geometry, structure and form will be the same. The form will be understand like a fluid concept, in which is more important to provide the empty in the structure that providing the masses. The future of architecture is the lightness. This paper presents a synthesis of the art state of the set of technical solutions to the design of architectures based on geometric deployable structures that will be applied to the building construction. The condition of the transformable forms will characterize the innovative production systems of contemporary architecture. This study provides a strong documental foundation for research on the significance of new structural and constructive systems in the production of the current deployable architecture.

1. Introduction

This paper presents a serie of transformable architectures that have been thought to this world in which we live and which requires of rapid architectonical solutions. There is awareness of the important of the development of social architecture, emergency architecture solutions (like field hospitals) and the need of working in the materialization of new temporary expositive spaces. The objective is studying the different contemporary manifestations in order to approach them to different spaces and places that do not have an adequate temporal architectural infrastructure or fast assembly by transformable structures. An alternative to conventional spaces will be proposed, both in rural areas, depressed neighbourhoods or city centres, as well as exhibition spaces or for art. It is gathered for the approach of these transformable architectures to the architects, artists, engineers and general public. Connections between artistic and architectonical practices will be promoted in order to encourage the discussion and reflection about the limits between the temporary or ephemeral and the durable in contemporary architectural creation.

It can be mentioned as exponents of this field of structures in the years 50-60 Stephane du Chateau, R. Buckminster Fuller, R. Le Ricolais and the great animator Z. S. Makowski. Later on, there will be exponents such as Florencio del Pozo, Pablo Bueno, José Calavera, Álvarez Castelao and Francisco Rius, Juan Margarit and Carlos

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**Corresponding Author:*
Mª Dolores Álvarez Elipe,
CEIPSO Salvador Dalí, Spain;
Email: mdolores_500@hotmail.com

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Buxadé, Félix Candela, Emilio Pérez Piñero, Escrig, Sánchez and Valcárcel, Chuck Hoberman, Carlos Henrique Hernandez, Luis Sanchez Cuenca.

Solutions for the creation of a transformable and functional architectonical space will be looked for. These solutions are characterized by their easy storage, practicality and versatility. The design must take into account the ease of transportation, assembly and disassembly because of its temporary or itinerant nature in many cases. The design must also value the proposal sustainability and the utilization of durable materials to the outdoors. It will be values as the contrast the flexibility and the adaptability with the lowest possible cost and complexity.

To a variety of possible sizes we have to add the multiplicity of morphologies, which give us a lot of possibilities to work and apply on architecture, generating dynamic architectures with a variable form and a lot of news possibilities. The formation of ordered structures which we are going to work is the result of collective processes of repetition of the unity. In these systems we have scales from the size of a single unit to the scale that characterizes the entire group; in these cases the individual behaviour indicates nothing - or very little - of what happens to the collectivity. These ordered structures, generically, are called patterns.

The research is based on mathematical and geometric basic rules, in which the problems of form are in the first topic mathematic and geometric problems, and the problems of growth are, in fact, physic problems, because the matter reflects physic laws. Therefore, the emergence of ordered structures is a result of physicochemical processes, and like some of the laws that govern these processes are expressed in mathematical terms, then, in the final analysis, the underlying mechanisms which explain the appearance of structures are grounded in maths.

2. Deployable Structures

The evolution of transformable bar structures will be studied in order to know the innovations than have been created. All of this is possible because of the study of existing patents.

During 50 and 60 years, transformable structures for architecture were begun to be investigated and worked. There was a true fever in patenting solutions corresponding to geometric dispositions, constructive systems and design of components (especially pieces of knot). These systems increasingly were more complex of execution but of more rational and versatile use.

The first deployable structure patent is found in 1944, with the “Improvements in supports for tents, marquees, temporary bridges and other portable structure” patent, shown in figure 1. This patent consisted in a long cannon vault compossed by a sucession or lowered and folding bows. So, speaking about deployable structures is speaking about a relative novel discipline.

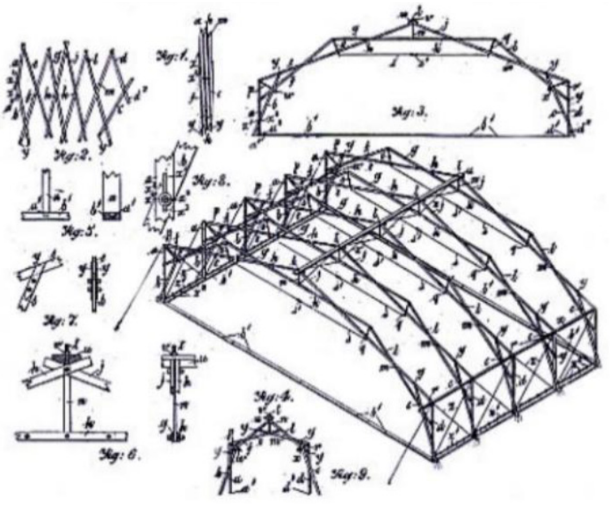

Figure 1. Improvements in supports for tents, marquees, temporary bridges and other portable structure. Barde Salden Watkins patent, 1944

R. Buckminster Fuller can be cited as a great exponent of this discipline of structures in those years. Fuller develops his first geodesic dome patent in 1951 and he will follow studying this type of structures along his professional career. An important example of this type of dome is the USA Montreal Pavilion EXPO1967, shown in figure 2. The building originally formed an enclosed structure of steel and acrylic cells, 76 metres in diameter and 62 metres high.

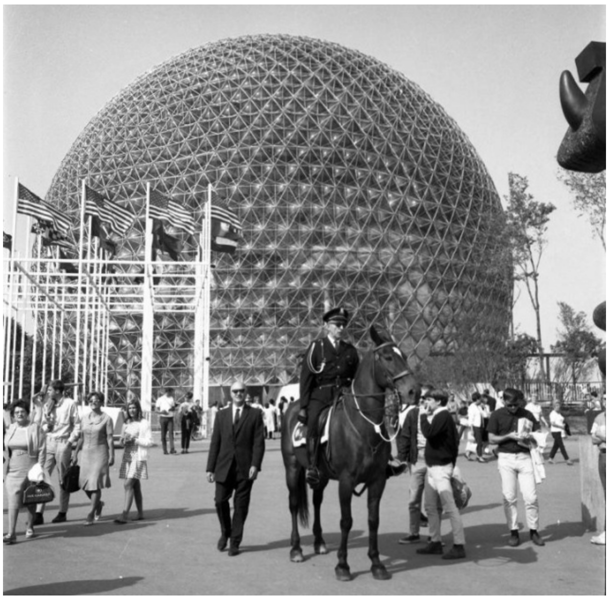

Figure 2. USA Montreal Pavilion EXPO1967. Buckminster Füller, 1967

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The geodesic dome can seem an alchemist recipe, but it is necessary to obtain a fully triangulated structure. So, it is necessary to avoid the flexion efforts in the bars. The innovation consists in the development of the structures that work to simple efforts. The structure is designed by division on smaller triangles following an order (more or less triangulations) any triangle of one icosaedrum (figure 3). After, its vertex has to be projected over a sphere, defining a determinate number of bars.

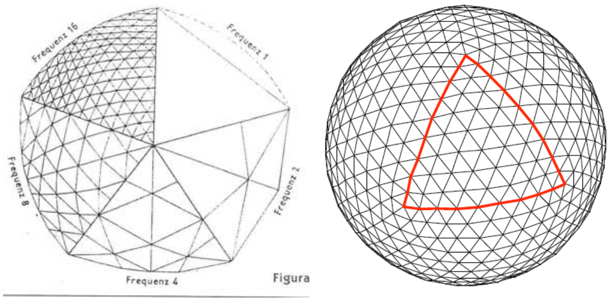

Figure 3. Icosaedrum division in patents (left) and icosaedrum division in construction (right), R. Buckminster Fuller

It would have been simpler at first directly projecting every face of the icosaedrum over the sphere and dividing the resulting curve (that it is a maximum circle) in equal parts. But doing things like that, the maximum circles are not found by three in three at the nodes and the structure is not completely triangulated. So, flexion efforts and a high number of knots and bars are produced.

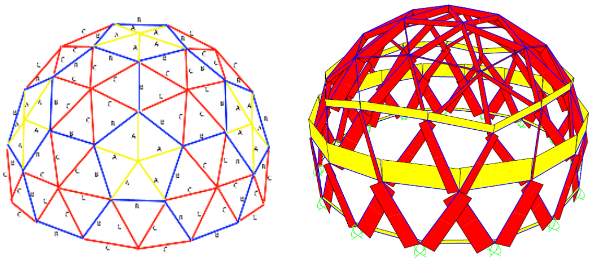

Figure 4. Geodesic dome realized with 3 different dimensions of the bars (left) and traction (yellow) and compression (red) simple efforts in a geodesic dome (right), own elaboration

A new way of thinking is found with R. Buckminster Fuller. He discovered by examining traditional constructions that most of the constructions were focused on the right angles and square configurations. He understood that the first humans developed this construction mode without much science. They simply stacked stone on stone. This simple system was acceptable only for small structures.

But Fuller discovered that the compression fort which caused the failure of heavy walls was always balanced by an equal amount of tensile force in the structure. In fact, he discovered that a structure will collapse if a tension and compression are not perfectly balanced. Fuller tried to employ the forces of tension in his new idea of construction by seeking always the maximum efficiency. Geodesic structures (figure 4) were the result [1].

His declared purpose was to cover the largest amount of land with the least weight. Fuller claimed to have achieved it with less than 4 Kg/m^2. He made it by construction of a generally spherical shape which structural elements were interconnected in a geodesic design of maximum circles by forming a triangular grid that was covered with a plastic sheet. Geodesic domes correspond to the biggest structures that can be constructed with the minimum possible amount of material. They are economics and quick to build too.

Fuller was a visionary that promoted projects which completely reconsidered the parameters of everyday life. Geodesic domes were born by his passion of creating an alternative system of geometry. He had capacity to forge inspiring and transformative ideas. Two of the most contemporary concepts of our time, "sustainability" and "innovation", would not have existed without his influence. He argued that the best teacher of creators must be nature.

A type of molecule formed exclusively by carbon atoms (carbon C60) bears the name of Fuller. The fullerenes are known just like that by its similarity of these molecules with the domes that Fuller designed (development equal to the nature). The geodesic structure that it is found inside of the cytoskeleton is a classical example of a pattern that is found in nature in different scales. The spherical groups of carbon atoms that are called “buckminsterfullerenes” or “buckyballs” exhibit geodesic forms. The virus, enzymes, organelles, cells and other small organisms also exhibit geodesic forms. All these entities stabilize themselves in three dimensions similarly when arranging its parts to minimize energy and mass through continuous tension and local compression.

The benefits of the geodesic structure are:

(1) Lower initial costs:

(2) Reduction in material costs

(3) Reduction in energy costs

(4) Reduction in workforce costs (faster, easier, simpler).

(5) Security: resistance to winds, storms, earthquakes and snow. As the wind blows more, it surrounds the structure and affirms it more to the ground because the structure has no suction surfaces. No covered structure is so stable and strong.

(6) Structural resistance: The geodesic form optimizes the loads by displacement of forces along all the structure.

(7) Concentrator of light and heat.

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(8) Lower wall surface exposed to the exterior in relation to the covered surface.

(9) Clear interiors.

Robert Le Ricolais (1894-1977) ideas can not be left unmentioned. R. Le Ricolais questioned the notion of form as something static. He understands the form like a fluid and in movement concept. Ricolais [2] tries to discover the relationship between structures extracted from nature (where it finds principally complex models of organization), and the structure of the forms constructed by the humans (figure 5). The idea that it is more important to provide the empty in the structure that providing the masses appears in his new structural concepts. The structural art consist of how and where to collocate the holes. It is an idea tremendously linked with every form built, because it implies building with holes, building with hollow material and building with hollow and resistant, but weightless structures. The future of architecture is the lightness.

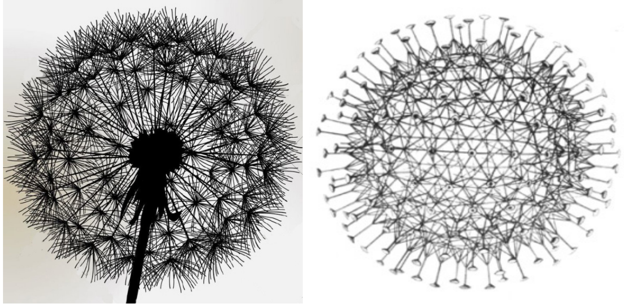

Figure 5. Flower of dandelion (left) and 3 Lattice System (right), R. Le Ricolais

In Spain, Florencio del Pozo, like teacher and designer, introduced this area of the structures. Pablo Bueno topped off his engineering studies with a flat meshes investigation. Later, he and José Calavera projected and constructed some of these meshes. Ignacio Álvarez Castelao and Francisco Rius were pioneers in providing solutions of spatial structures in their projects too. At the beginning of the 70s, the space meshes appear in architecture, by Juan Margarit and Carlos Buxadé. Felix Candela, from Mexico and USA, always exerted influence on Spanish scholars. All these initiators are linked to the academic world and contrast or learn from it their solutions.

Emilio Pérez Piñero [3] is not based in investigating theoretical models speaking as much of design as of calculation. From the beginning he fabricate them because he does not have baggage provided by others in which rely on because his design is totally new. But it is not a difficult work for him. He builds their models with his manual ability and his spatial vision. He developed his work alone and he protected his findings by patents. He wanted to commercialize his structures and he dedicated his professional life to this purpose.

The information that is usually reflected in plans about his realizations is not abundant and accurate. However, mock-ups and scale models or pieces of them exist. In order to make transmissible his realizations is necessary draw and defining them in large part. Although mock-ups and models could be handled, it is the best way to do it accurately and rigorously the transmission of his work.

His characteristic invents are:

(1) Deployable straight bar structures formed by beam modules.

(2) Deployable broken guideline bar structures formed by beam modules.

(3) Demountable reticulate domes.

(4) Autodeployable domes.

(5) Retractable domes.

(6) Deployable structures with rigid autofoldable cover.

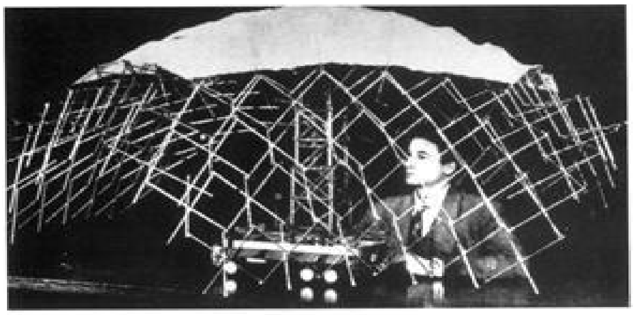

Figure 6. Pantograph for the folding itinerant theatre. Pérez Piñero, 1961

Emilio Pérez Piñero and Félix Candela [4] joined professionally towards a promising path. They looked for the resistant problems. That is to say, they looked for the form of the problems and did not looked for the problems of the forms. This generated an elusive and extraordinary game with the laws of gravitation.

In the text “Reticular structures” [5] the following words appear:

“[…] It is an initial premise the need to adapt and twin in an insoluble bond shape and material. […] The form has to be studied in order to obtain the most adequate tension distribution. In the material will be its mechanical qualities and density, in accordance with the chosen form and the tensions that occur in it, which will determine its choice. Structure in form is what makes its subsistence possible as such. In the first concept structure and form are identified. […] The mesh appears like general shape and it is assumed predetermined and fixed previously. The bar is a condensation of mass in the line of the force. The holes are a suppression of inert mass.”

In this same text [5] Emilio Pérez Piñero also frames and analyzes the characteristics, evolution, types and future of the reticular system. In this text can be read:

"[…] In the conception, design and execution of a reticular structure the following phases appear:

(1) Determination of the general form of the set.

(2) Determination of the grid, arrangement and length of the bars. This can be called "Geometric calculus of the structure".

(3) Mechanical calculus and dimensioning of the bars.

(4) Constructive resolution of the connection of the different bars.

(5) Effective formation of the structure in its location with the assembly of its elements."

This is the process that is intended to follow in the subsequent geometric evaluation of the unfoldable structures studied.

It can be said that Emilio Pérez Piñero is the inventor of the deployability, based on the modularity, light weight and transformability concepts. His principal innovations are the spatial deployable structures of bars and through articulate knots from the scissor mechanism formed of three or four bars linked in an interior point. This system has not been documented before and he protected it by patents between 1961 and 1972. Nowadays, there are solutions of him that there are not understood or exceeded by posterior investigators.

The deployable structures investigated are characterized by the use of the bars with collocation in "x" in the thickness of the structure. It generates plane and curve surfaces. In both cases the movility is produced in the mechanism phase and they have to be stabilized later.

The folding itinerant theater (figure 6) consists of a flat cover structure. This structure is foldable and consists of bars, perimetral open triangular supports and bracings, and four special square supports. As a whole, the structure covered an area of nearly 8,000 sqm.

Figure 7. Transportable pavilion "Twenty five years of peace". Emilio Pérez Piñero, 1964

In 1964 a transportable pavilion (figure 7) was in charged to him to celebrate the twenty five years of peace with Franco. In the antipodes of the model presented in London, he resolved the project with a plane of double layer structure. The articulated knot facilitated to a large degree the transport. The pavilion also could change the emplacement and the form. It has outdoor places to take advantage of the spring and summer weather in Madrid. But in San Sebastián and Barcelona it presented a compact form [5].

The envelope to the outdoors exposition "Twenty five years of peace" has a stabilization system in which first of all the structure is unfolded. Later, a serie of bars is added in top and lower faces until complete five pairs of laces in one direction. Two more serie of bars are added occupying the extreme edges in the other direction. This direction also receives uprights until all the aristas of these edges are triangulated.

The dome of the theater of the Dali Museum in Figueres (Girona) also is found among his works (figure 8). It is a polyhedral dome banked, based on a spherical icosahedron of fourteen meters in diameter and with a height in the key of ten meters, sitting on asymmetric pendentives of spherical direction of thirty-four meters on each side.

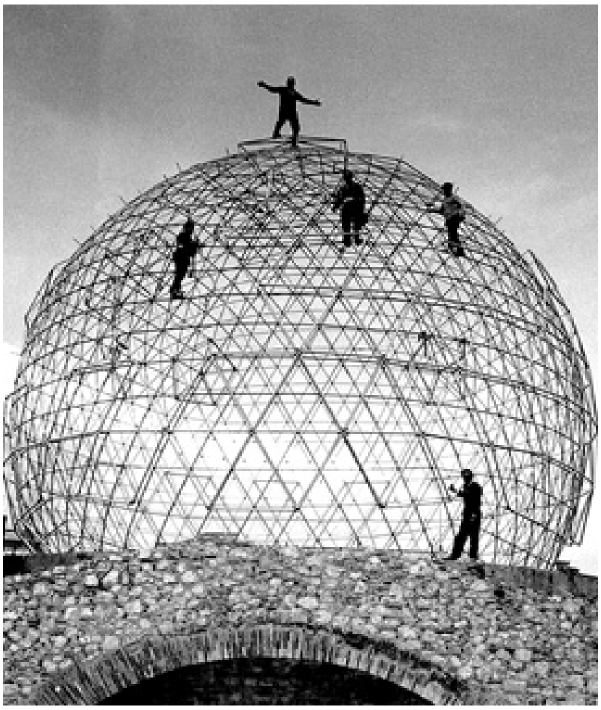

Figure 8. The dome of the theater of the Dali Museum in Figueres (Girona), Emilio Pérez Piñero

Lina Puertas, in her thesis about Emilio Pérez Piñero, presents a mathematic solution and an informatic program to the complet geometric definition of the used mesh to modelize these deployable structures.

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Albert Moore appears like inventor of the "Pre-assembled structural framework" patent that was granted in 1967 (figure 9). The innovation is the triangulated double-curved vault.

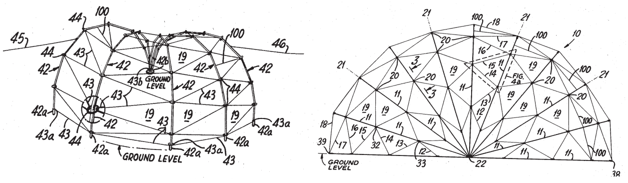

Figure 9. Pre-assembled structural framework. Albert Moore, 1967

Teodoro Zeigler develops some patents of deployable structures since 1977, which innovation are the articulated through knots with scissor type system. The final design is a triangulated dome formed by the bars without bracing like the patent "Folding self-supporting structures" shows (figure 10).

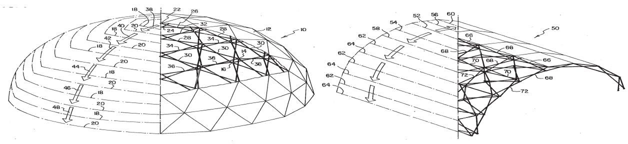

Figure 10. Folding self-supporting structure. Teodoro Zeigler, 1977

More recently, about 1980, Santiago Calatrava [6] preferred to use articulated arms instead of scissors in proposals that made him famous like the foldable entrance for the Ernsting store, in 1983, and many others. In 1988 he presented his thesis "On the folding of the trusses", in which he realize a geometric study of the deployable structures from their rhomboidal, polyhedral, cubic and spherical modules (figure 11). And later designed a lot of movable roofs and cantilevers based on articulated single arms.

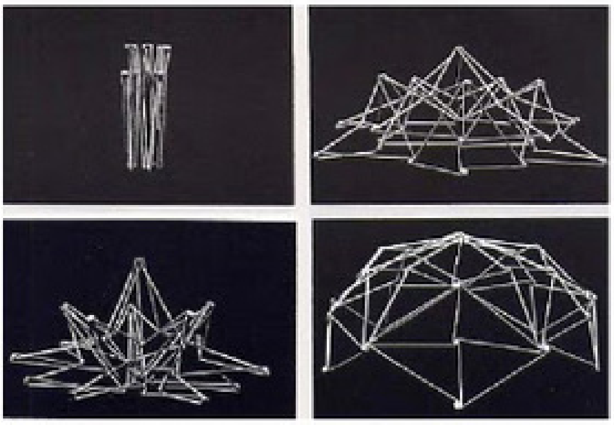

Figure 11. Images of "On the folding of the trusses". Santiago Calatrava Thesis, 1980

Carlos Henrique Hernández [7] continues the works of W. Zalezwky. Between 1987 and 1992, he designed and built the Venezuela Pavilion at the EXPO 92 in Seville based in the accordion system (figure 12). A model based on accordion-like folding system was conceived to cover a span of 30 X 20sqm. He developed the hinge knot and resolved problems of construction, assembly and rigid enclosures. He also developed proposals based in squares meshes like STRAN 1 and STRAN 2, in which developed the scissor knot and the long barrel vault.

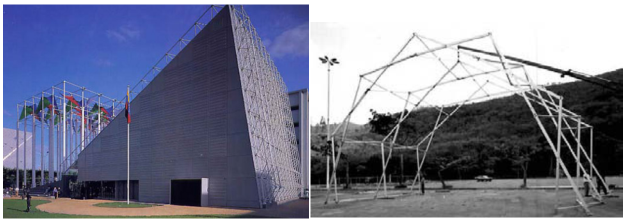

Figure 12. Venezuela Pavilion at the EXPO 92 in Seville (left) and STRAN 1 (right). Carlos Henrique Hernández, 1992

While Emilio Pérez Piñero worked on scissors with three or four arms, the team formed by Escrig, Sánchez and Valcárcel [8] proposed to use two arms scissor as the basis for their designs. The main achievement of this team was the completion of the swimming pool roof in San Pablo sports area in Seville (figure 13). The dimension to cover in plan was approximately of 60x30 sqm.

Figure 13. Swimming pool roof in San Pablo sports area in Seville, Escrig, Sánchez and Valcárcel

Chuck Hoberman is the inventor of the eccentric scissor and scissors trains, which permitted to make more compact the bundle when folded and create completely closed polihedra (figure 14).

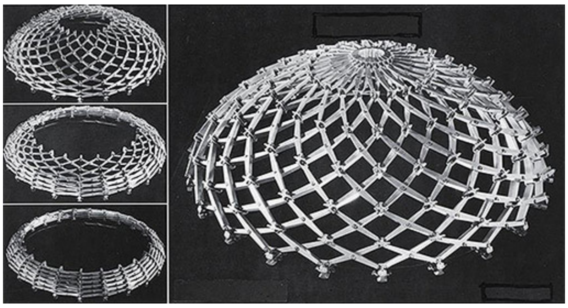

Figure 14. Sphere of Hoberman, Chuck Hoberman

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A lightweight, rapid-erect shelter system using a new combination of composite materials and fabric diaphragms in a truss support system has been developed by N. K. Burford and F. W. Smith [9] in response to changes in military requirements (figure 15). The authors focus on the problems encountered in the development programme and the innovation process, highlight how these problems were overcome and detail the benets which were created. In particular, the resulting tent incorporates lightweight sprung glass reinforced composite beams, post-tensioned by a fabric diaphragm. The new shelter uses a minimum number of these lightweight, rigid components and consequently achieves a reduction in weight, erect and strike times and packed bulk through its innovations.

Figure 15. Revised structural configuration of full scale prototype shelter, N. K. Burford and F. W. Smith

Luis Sánchez Cuenca developed a complex geometric theory for building any kind of deployable surfaces (figure 16).

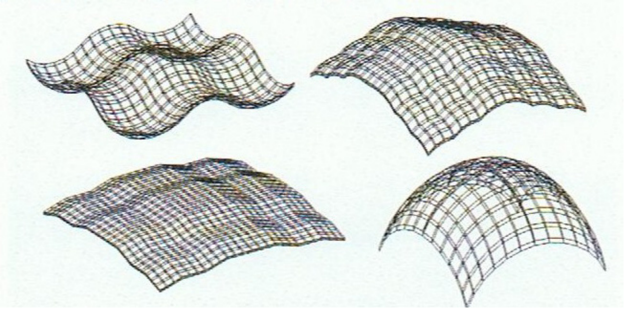

Figure 16. Proposal made to generate arbitrary forms, Luis Sánchez Cuenca

Marta Balaguer Sala and Ramón Sastre i Sastre [10] investigate the systems of bars in x with intermediate hinge, also called SLE (scissor like elements) (figure 17). It has been proved possible to obtain different formal alternatives with a single structural solution, by making modifications to add a DOF (degree of freedom) to SLE base unit. So, the new typology is the telescopic bars articulated in x.

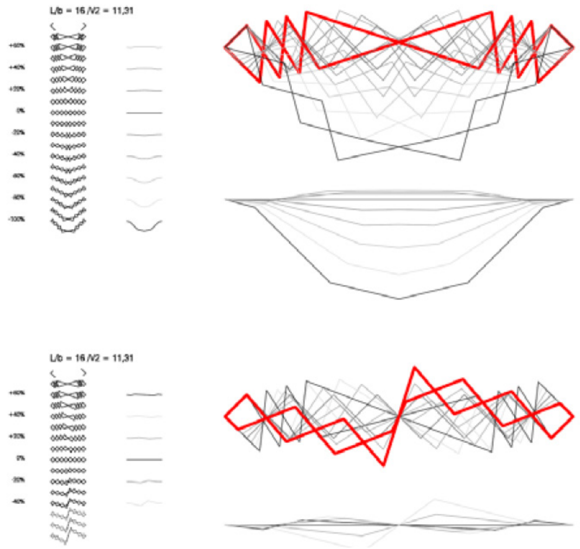

Figure 17. Transformation process of the transformable system with telescopic bars articulated in x, Marta Balaguer Sala and Ramón Sastre i Sastre

Daniel Enrique Gómez Lizcano [11] develops mobile systems with one degree of freedom (1DoF). Al least two polygons can generate them: quadrilaterals and triangles. The first is the result of articulate scissors like elements, transmitting the efforts from one module to the next uniformly (figure 18). The second consists of the combination of articulated and sliding systems, by incorporating a guide element in which deformable triangles are inscribed with compression operation (figure 19).

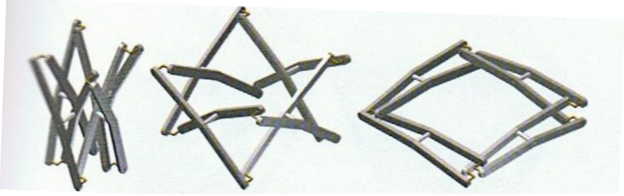

Figure 18. Movement of a truncated square based pyramid, Daniel Enrique Gómez Lizcano

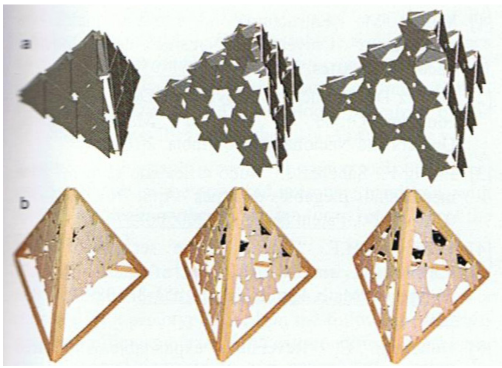

Figure 19. Analysis of the movement transmission between faces: (a) Articulated joints, (b) Slidable framework. Daniel Enrique Gómez Lizcano

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Antonio Ponce García and José Sánchez Sánchez [12] generate curve surfaces by scissor mechanisms in x form (figure 20). Those meshes that can be curved in only one direction give rise to cylindrical surfaces whereas those one that can be project, bending in two directions, become a double-curved ones. The proposal of their work is the resolution of the generation of these rectangular module meshes as regular frustoconical surfaces.

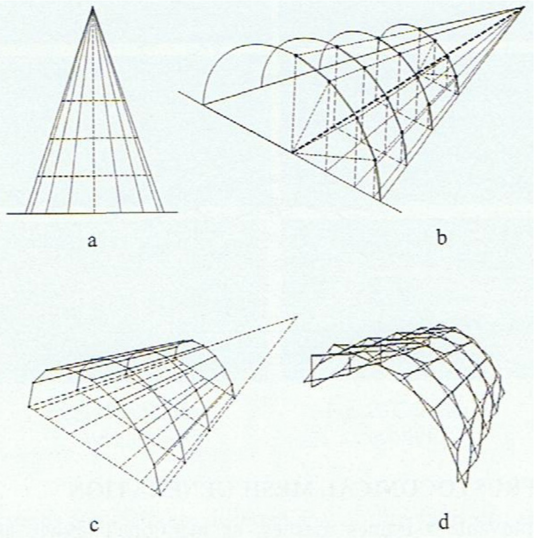

Figure 20. Frustoconical mesh generation, Antonio Ponce García and José Sánchez Sánchez

Cristina Ramos Jaime, Antonio Maciá Mateu and José Luis Oliver Ramírez [13] focuse on the development of a solution to achieve the curvature for deployable spherical grids, which aim is to simplify the constructive process (figure 21). A system that allows the use of straight bars with central articulation and that takes into account the size of the joints is proposed. The nodes between cross-pieces are formed by two rings with different diameter according to the angle required in each connection.

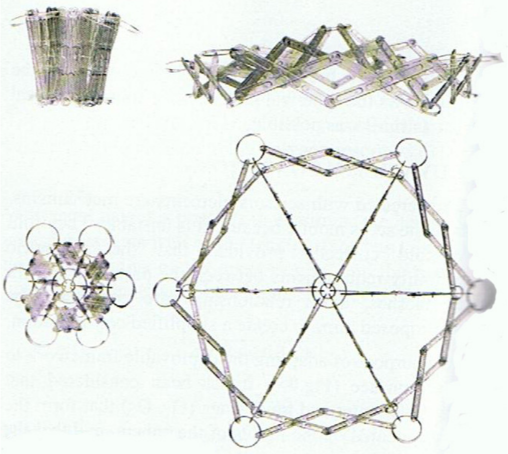

Figure 21. Curved grid unit, Cristina Ramos Jaime, Antonio Maciá Mateu and José Luis Oliver Ramírez

Omar F. Avellaneda L. [14] addresses the problem of dynamic structures seen form their structural morphology and function in the field of architecture (figure 22). The objective of his research is to study the solution of the enclosures for deployable structures, adopting textile systems for such approaches, and design coordination for the structure and its enclosure.

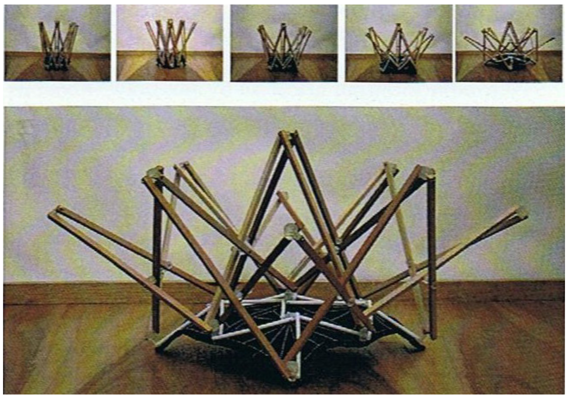

Figure 22. Model with stiffening membrane system synclastic, Omar F. Avellaneda L.

Koray Korkmaz, Gözde Susam and Yenal Akgün [15] introduce a novel 8R reconfigurable mechanism which can meet different hyperboloid paraboloid surfaces (figure 23). The novel design utilizes the overconstrained Bennet linkage and the production principals of ruled surfaces. They improve these systems with their novel mechanism.

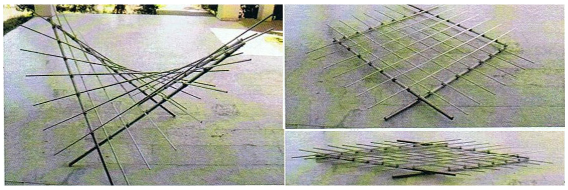

Figure 23. The model shows the transformation capacity of the novel mechanism with fourteen intermédiate links, Koray Korkmaz, Gözde Susam and Yenal Akgün

Yohei Yokosuka y Teruo Matsuzawa [16] present a system called a multilink spherical joint, which is a novel mechanism that allows triaxial rotation of members (figure 24). It can form ideal structure systems of variable geometry without small offsets between the rotation centers of the links. This system is only a prototype, and it was not built as architecture.

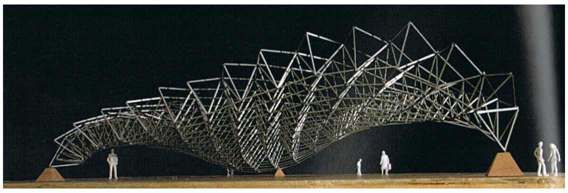

Figure 24. Study model of variable-geometry structure, Yohei Yokosuka and Teruo Matsuzawa

Rodrigo Ramos Jiménez [17] has like objective finding the proper geometry for deployable structure of x-frame and an opening system which allowed us to install a covering in a few minutes (figure 25). He also wanted it to be modular in length. He obtained the conclusion that the best they worked was formed by trunk of cones formed by trapezoids and rows of triangles at the base. This system is only a prototype, and it was not built as architecture.

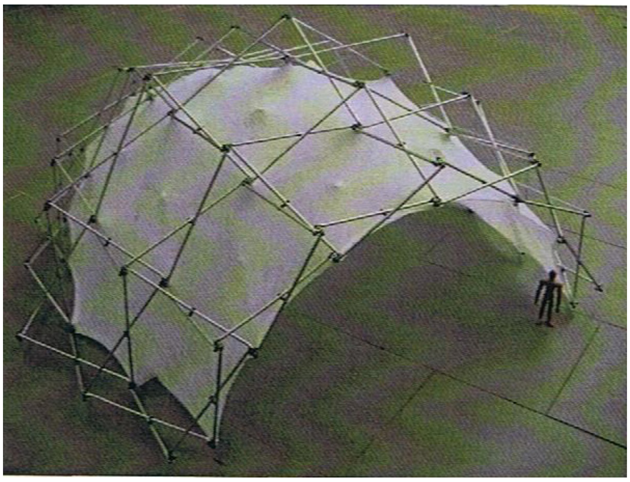

Figure 25. Model of dome made of two trunks of cone, Rodrigo Ramos Jiménez

Lara Alegria Mira, Niels De Temmerman and Ashley P. Thrall [18] develop transitional shelters which can be rapidly deployed and reconfigured afterwards (figure 26). Deployable structures based on scissor elements are lightweight and provide a high volume expansion after deployment. The prototype to architecture was built before 2017 [19].

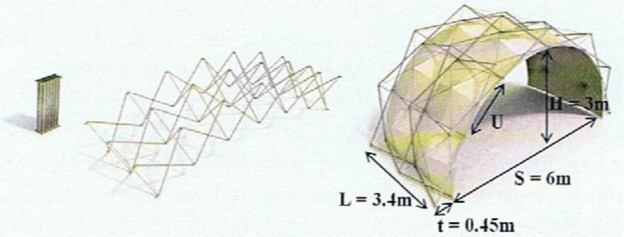

Figure 26. The concept for a shelter uses deployable scissor arches with a membrane. Dimensions are indicated at the right. Lara Alegria Mira, Niels De Temmerman and Ashley P

Daniel S-H Lee, Olga Popovic Larsen and Seung-Deog Kim [20] present a study investigating into a more effective design of connection joint for scissor-type deployable structure (figure 27). The main objective is to look into; 1) the design to minimise the structural deformation and hence the induced stress level during deployment, and 2) the simplest solution for the practicality of analysis and construction.

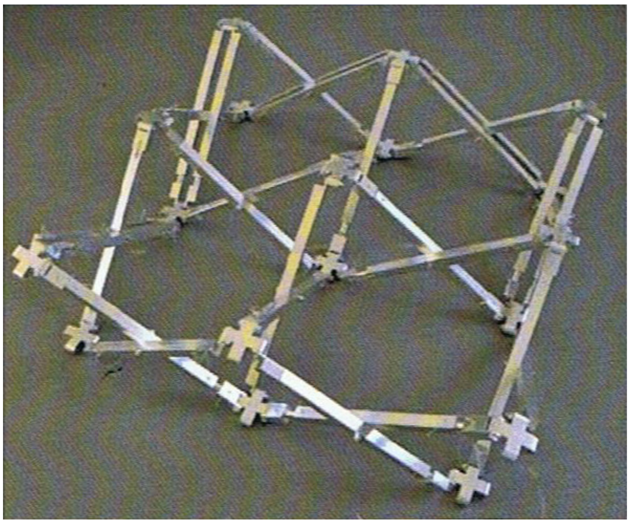

Figure 27. The physical prototype, Daniel S-H Lee, Olga Popovic Larsen and Seung-Deog Kim

Carlos Cesar Morales Guzman [21] develop an experimental investigation of organic geometry in architecture, consequently reference was taken as fractal geometry, as this helped to form a flexible and adaptable in nature are versatile structures adapt to highly variable contexts, noting that concept is embodied in the application of a light and retractable structure (figure 28).

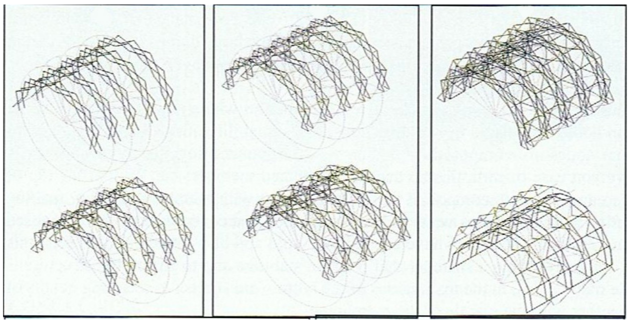

Figure 28. Development of organic according to the geometry generated by forms and modular Member for their standarization and iteration. Morales, 2010

Natalia Paola Torres Londoño [22] describes the design process for a deployable, movable stage that can be adapted to different spaces and uses (figure 29). The structure's configuration was developed through the analysis of the various key structural systems enabling it to be opened, closed, and transported without the need to be disassembled. The research was based on the study of scissor systems, folding and on the design of folding-membrane deployable structures.

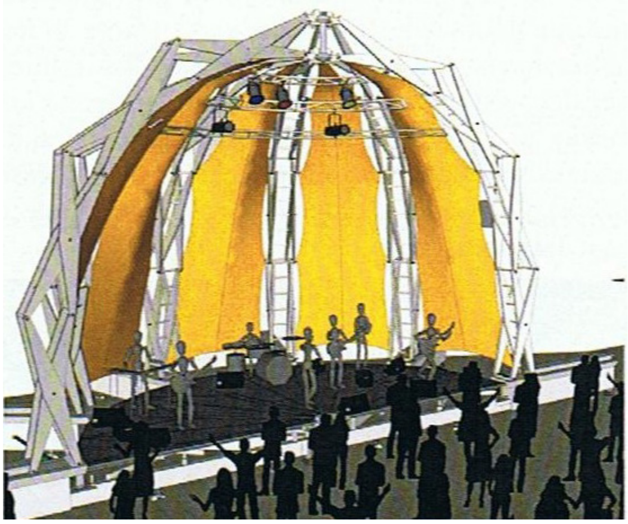

Figure 29. Folding stage for cultural events, Natalia Paola Torres Londo**ñ**o

Charis J. Gantes, Konstantinos E. Kalochairetis and Yenal Akgün [23] develop deployable structures that can be defined as structures that can be transformed from a closed compact configuration to a predetermined, expanded form, in which they are stable and can carry loads. In order to achieve deployability significant restrictions are imposed upon the possible geometric forms as well as the arrangement of structural members.

Rodrigo García Gonzálezinnovates by making rigid the structure of its own geometric configuration once deployed without requiring external elements (figure 30). His design can be used to high buildings. He incorporates the concept of fractality to the deployable structures.

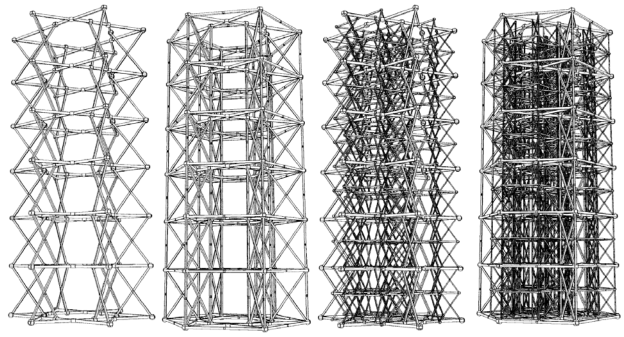

Figure 30. Fractal expanding structural system, Rodrigo García González

Nowadays, AKT, Adler, Karan and Taylor, study the project that FOA developed based on hexagonal pieces to an idea of prototype (figure 31). Any sizes of hexagonal panels provided with curved and flat inner walls were developed. The problem was the links. The resolution was taken them away from the nodes.

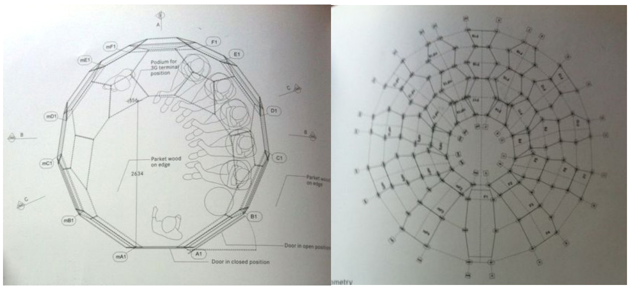

Figure 31. Pods, Hexagonal Glass and Glass Joint HUTCHINSON 3G. AKT, Adler, Karan and Taylor

Lisa Iwamoto [24] also develops some deployable structure, like the “Digital Weave” (figure 32). The exploration of expandable surfaces and social issues of homeless was experimented on the design of a performance art centre. The idea was the expandable mechanism was able to provide a multifunction surface which allowed different programme to happen. Part of the facade could be open during certain period of time to create an outdoor performance area. When the façade was closed, it can used as rehearsal room and also and exhibition space. This transitory event was the key to create public awareness of homelessness in the surrounding community.

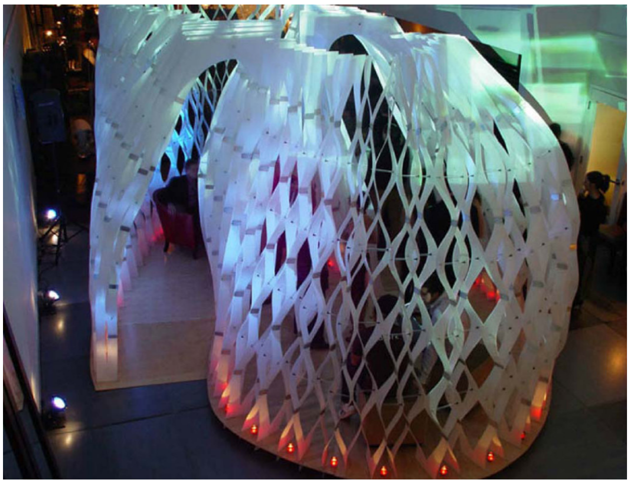

Figure 32. Digital Weave, Lisa Iwamoto

Finally, it should be emphasized that many of these deployable structures are based on tensegrity systems. A tensegrity is a bars and cables structure that only works in compression and traction. The bars and the cables are equilibrated between them. The growth of the structure is apparently messy.

A tensegrity is a closed structural system in which three or more elements are compressed between traction elements. Traction elements generate distance between compression elements and it generates a triangulate system which cancels the forces by keeping it in perfect balance. That is, tensegrity is not based on weight and thrust strat-

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egies. Tensegrity is based on equilibrium tension systems. They do not depend on external efforts like weight or gravity.

Tensegrity structures have the capacity of giving a global response as a whole. Every punctual load to which they are subjected is uniformly transmited and absorbed for the whole structure. Its stiffness also increases as the load increases.

In terms of their structural properties, tensegrities stand out by their lightweigh in comparison with other structures of similar resistence. They have a high carrying capacity if they are compared with other structures of analogous weight.

Tesegrities have self-equilibrium. They require of no anchorage or fixation to maintain its shape or geometry. They are stables in every position.

If the prestressing of a tensegrity system is greater, its bearing capacity or resistant capacity will be greater.

Because of the compression elements are no continuous, they only work locally. They also are resistant to torsion and buckling because of the small section of their elements.

Tensegrities have the property of synergy, in which the behaviour of all the set is not predictable from the behaviour of its individual components.

The rigidity of the structure depends on the materiality and the links.

These tensegrity structures are in relation with the principles of nature. The cell can be considered a tensegrity system. The cytoskeleton of cells has the same role as bars and cables in tensegrity structures. The cytoskeleton balances the stresses that giving shape and stiffness to the cell.

Tensegrity structures have a serie of advantages and disadvantages:

The advantages are:

(1) They do not present points of local weakness.

(2) It is feasible to use materials in an economically and cost-effectively form.

(3) Tensegrities do not suffer torsion, and buckling is a phenomenon rarely present in them.

(4) It is possible to create more complex systems by the assembly of simpler ones.

(5) For large-scale structures, the construction process would be facilitated by the absence of additional scaffolding. The structure itself serves as a scaffold for itself.

(6) In folding systems, only a small amount of energy is needed to change its configuration.

The disadvantages are:

(7) The tensegrity groups have yet to solve the problem of congestion of bars. As the size grows, their mounts begin to interfere with each other.

(8) A relatively high degree of deformations and low material efficiency are observed, as compared to conventional geometrically rigid structures.

(9) The complex manufacture of these constructions is a barrier for the development of the same ones.

(10) To maintain the self-tensioning state, it is necessary to subject them to a prestressed state which would require very high forces for their stability, especially for those of large dimensions.

3. Conclusions

By the analysis of submitted architectures is observed that all of them have their origin in a geometric triangular pattern. This pattern is, geometrically speaking, totally stable.

In the developments studied are presented the scissors mechanism in the repetition of structures applying certain turns in order to obtain the pliability. We obtain with these mechanisms lightness structures.

These structures are subject only to simple tensile and compressive stresses.

From all this we deduce that this accommodation from pliability to architecture is totally viable. New structures verify very lighness structures that we find easy to transport. Triangulation is always presented like something totally basic.

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