Keynote Address

General survey of deployability in architecture
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1. INTRODUCTION.

Proposals that we know today as very advanced and technologically complexes, based on deployability are nevertheless as old as the civilization is.

From the moment when men abandoned caves and caverns to search for better life, they need shelters built by them most times of rapid assembling made with matherials found anywhere or by pieces easy to be transported.

Architecture built with earth, straw, branches or skins is the remote precedent of movable and rapidly assembled structures and is related directly with the object of our recent researches.

Fig. 1. Hunter Chair.
Fig. 2. Babilonic Terracota 2000 B.C.
Fig. 3. Senefer Tomb. 1460 B.C.
There are not too much ancient examples to be explained in detail although we are sure that there were usual deployables objects and structures.

“Egyptian chair” is still in use known as “Hunter chair”. It is built with three rods connected at an intermediate point as shown in Fig. 1.

“Scissor Chair” is represented in the oldest engravings. Fig. 2 shows a babilonic terracotta tablet and Fig. 3 an Egyptian fresco. The umbrella can be also an Egyptian invention because its similitud with the palm tree. But it is in the Middle East where it was very well described. Figs. 4 and 5 shows clearly even the sliding mechanism of folding.

Fig. 4. Assurbanipal 680 B.C.

Fig. 5 Persépolis 480 B.C.

Fig. 6 and 7. Deploying a Sail. Ipi Tomb. IV Egyptian Dynasty.
In the great scale were the naval machinery where deployability required highest technology. Masts, sails, nets and decks require complex mechanisms to fold and to extend them. Figs. 6 and 7 show complicated assemblings for egyptian boats.

The art of war is other of the uses where lightness and movility were demanded. They are a lot of low reliefs that represent tents and camps (Figs. 8 and 9).

But may be that the most astonishing mobile structure built in the antiquity is the roman “velum”. It is well known that most of the theaters and amphitheatres were covered eventually by inmenses awnings that, as in the Coliseum, extended till 20,000 sqm. in only one piece. Fig. 11 shows the only drawing remaining of this roofing system. Fig. 12 show the Roman Coloseum.

The medieval times were rich in luxurius tents as well in the Christian as in the muslim fields.

But they were not armies nor conquerors who developed the most clever systems. They where nomads, shepherds and tribes who invented optimiced mechanisms to live inside, to mount and pack them and to carry them on their beasts.
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The mughal folks use the yurta yet. It is a tent stiffned by means of diagonal struts that move freely in a rhombic grid and that can be folded in a bundle or extended as a fence. After deployment the structure is covered with skins and it is tied with strings (Figs. 12 and 13).

![Fig. 12. Mugal Yurta](image12.png) ![Fig. 13. Transporting a yurta.](image13.png)

The berebere tent is a tensile fabric with a complex surface that defy the storms winds of desert with incredible simplicity (Figs. 14 and 15).

![Fig. 14. Berebere Tent.](image14.png) ![Fig. 15. Transporting a Berebere Tent.](image15.png)

The indian tipis are other example of clever structure. Ten or twelf strait long branches forming a cone and covered with buffalo skin gives a perfect shelter that ventile through the vertex (Fig. 16). When folded the tent structure is used as a transport platform where to carry all the belongings of the family (Fig. 17).

![Fig. 16. Indian Tipis](image16.png) ![Fig. 17. Transporting a tipi.](image17.png)
2. MODERN MOBILE STRUCTURES.

Medieval technique were highly sophisticated and the need of repeat centering and scaffolding of modular vaults justify the invention of movable and rapidly assembled platforms. Nevertheless not any drawing or textual record has arrived to us. It was in the Renaissance period when builders explained in detail the instruments and the auxiliary structures that they used. Francesco de Giorgio in the “codice Laurenciano” shows machines based in diagonal ties that pull or push to change the geometry (Fig. 18). But it is Da Vinci who more ingeniously planned new structural concepts. Fig. 19 shows a umbrella of great size. Fig. 20 shows a pantographic crane to lift weights. Fig. 21 shows a bridge executed with only one tipe of piece that can be executed with a minimum amount of time. Fig. shows a mobile bridge. Figs. 23 and 24 shows an articulated movable arm disposed to form his airplane. Others as Palladio (Fig. 25), Verantius (Fig. 26) or Primaticcio (Fig. 27) proposed bridges and trusses of great simplicity.

Fig. 18. Notebok Laurentiano By Francisco di Giorgio.
Fig. 19 and 20. Notebook Madrid I. By Leonardo da Vinci.

Fig. 21. Notebook Atlantic. Modular Bridge by Leonardo da Vinci.
Fig. 22. Notebook Atlantic. Mobile Bridge by Leonardo da Vinci.
Fig. 23 and 24. Articulated wings in Atlantic notebook by Da Vinci.

Fig. 25. Palladio Bridges.
Fig. 26. Verantius Bridges.
Fig. 27. X-Trusses in a engraving by Primaticcio.
The theatre was other field where easy mounting and desmantling structures are a first need. The Baroq scenery was of incredible complexity (Fig. 28). In the same way advanced the technices of scaffolding (Fig. 29).

As we began this text, domestic devices developed new applications of deployability. Fig. 30 shows a distaff and Fig. 31 a claw for hair.
3. ACTUAL DEPLOYABLE STRUCTURES.

Graham Bell was a new Leonardo who invented so many useful things that can not be related in this short paper. But his studies on modular space frames put him as a precursor of deployability.

As Schwedler with his regular spherical domes Bell’s frames were so light that only Fuller could surpass them (Fig. 32). Fuller was a mysthic that made religion of the geometry. His first geodesic designs were rigid (Fig. 33).

Fig. 32. Tower by Graham Bell.  
Fig. 33. Fuller geodesic dome patent. 

Fig. 34. Tensegrity poliedra by Fuller.  
Fig. 35. Foldable geodesic dome by Fuller.
But he advanced more and more in the way of rapid assembling and even of deployability. Three items are in favour of the pioneering of this inventor:

a) **The tensegrity poliedra** (Fig 34).

b) **The foldable geodesic sphere** (Fig. 35).

c) **The Flying seedpot** (Fig. 36).

But he never employed any of these solutions to a real construction.

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**Fig. 36. Fly Seedpot by Fuller**

**Fig. 37. Transportable exhibition Pavillion in 1964 by Emilio Pérez Pinero.**
Fig. 38. Deployable Roof for a 8000 sq.m. exhibition by Emilio Pérez Piñero.

Fig. 39. Self Stiffned spherical deployable dome by Emilio Pérez Piñero.
This is the reason why Emilio Pérez Piñero, the Spanish architect death in 1972 at 36 years old, still remains as the first and greatest of all structural designers in the field of modular and deployable architecture.

His first dome (Fig. 37) never was constructed but his 8,000 sqm pavilion was of great success (Fig. 38) as well as his geodesic polygonal dome (Fig. 39), and many other important inventions as the diaphragm dome. (Fig. 40).

With Emilio Pérez Piñero gone, we lost a guaranty of increasing discoveries. But other designers follow his track. Ziegler, in 1976 (Fig. 41), myself in 1980 (Fig. 42) and Calatrava in the same year (Fig. 43).

![Fig. 40. Diaphragm retractable dome by Emilio Pérez Piñero.](image1)

![Fig. 41. Geodesic deployable X-frame dome by Ziegler.](image2)
Fig. 42. Deployable X-frame icosahedron by F. Escrig.

Fig. 43. Deployable one layer grid truncated icosahedron by S. Calatrava.

Fig. 44. Swimming Pool by Taillibert. Paris, 1967.

Fig. 45. Open theatre in Bad Hersfeld by Frei Otto.
The eighties were prodigal of studies that let the deployability science ready to be applied to the real projects. References contain some of them.

In the recent years we can classify the tendencies in several branches:

a) **Tensile folding structures**. As Taillibert did on a swimming pool in Paris (Fig. 44) and Frei Otto repeat it in several proposals (Fig. 45). These are a kind of very easy movable structures capable of be folded in a little parcel.

b) **Tensigrity roofs**, proposed at first by Buckmister Fuller (Fig. 46) and put in practice by Geiger (Fig. 47). They are not movable structures but very easy to be mounted and dismantled.

c) **Retractable roofs**. Rigid Roofs built by parts can slide its components by traslation or twistiong overlapping then wen we want to open the cover or extending them on the area to cover to make a trussed conventional roof. The first great proposal was made by Allen in the Toronto sky dome on an area of 200 m. (Fig. 48) and the most spectacular solution is designed by Takenaka in the 220 m. Fukuoka Dome (Fig. 49). The systems proposed to solve this kind of structures are pincipally of four types: Cilindrical Telescopic, Spherical Telescopic, Fan Telescopic and Mixed Systems. Otherwise they have sepectacular appearance sometime as can be seen in Ref. 12.
d) **Foldable Structures.** Formed by hinged pieces that fold and extend like an accordion. Labinski & Deflon proposed an interesting solution never built as the Chicago Fan Dome (Fig. 50). The most important of this type of structures was the Venezuela Pavilion at the EXPO'92 in Sevilla by Hernández & Herminy (Fig. 51).

e) **Umbrella Structures.** They are mechanisms supported by a must that open and close by some sliding arrangement. Fig. 52 shows a mush ballon in the EXPO'70 at Osaka by Taneo Oki while Fig. 53 shows umbrellas in mosque of La Meca by Boda Rash.
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Fig. 52. Mush-ballon at the EXPO’70. Osaka by Taneo Oki.

Fig. 53. Solar Powered Umbrellas in La Meca By Bodo Rasch.

Fig. 54. Kuwait Pavillion at the EXPO’92. Sevilla by Santiago Calatrava.
f) **Mobile Structures.** They are similar to an animal body with bones, tendons, and muscles. Da Vinci was the first to propose such assemblies. In the actuality is Santiago Calatrava who better represents this tendency (Fig. 54).

g) **Deployable Structures.** They are bundles of struts hinged at the extremes in groups of three or more with a geometry compatible with a process of deploying. They can be of three main types:

- Collapsible grids because some bars have a central articulation that allow them to bend (Fig. 55).

- Un-hitched joint grids, where bars connected to a joint can be separated into two groups of them (Fig. 56).

- X-frames formed by groups of scissors of two or more arms. Emilio Pérez Piñero was the first to build some architectural proposals of this kind. In the actuality only Henrique Hernández have constructed some roofs of this type (Figs. 57 and 58) at different scales. Recently Hobberman have proposed an interesting Irish Dome with great possibilities to cover a circular area (Fig. 59).
Fig. 57. Stran Patent of a Deployable X-Frame by Henrique Hernández.

Fig. 58. Cover for a swimming pool at Sevilla by Escrig & Sánchez.

Fig. 59. Irish Dome by Hobberman.
h) **Lifting Structures.** Really they are rapidly assembling structures that can be mounted at the ground level to be lifted by means of jacks till its definitive position. They are a lot of ingenious systems by it is Mamoru Kawaguchy who has built the most impressive roofs (Fig. 60). Fig. 61 shows the Izumo Dome Stadium by Kajima.

![Fig. 60. World Memorial Hall in Kobe by Kawaguchy.](image1)

![Fig. 61. Izumo Dome Stadium by Kajima.](image2)

Our explanation about built or ready to be built structures is necessarily incomplete and we have forgot a lot of people which have collaborated in the development of the classification detailed above. It is impossible to relate in so short space the research of hundreds of designers and scientists. Many of them are not directly interested in architecture although all his proposals give profile to the building science. Researchers as McNoulty in Dublin. Pellegrino in Cambridge, Nooshin in Surrey, Motro in Montpellier. Slaich in Stuttgart, Zalewsky in Cambridge, Gantes in Athens, Chilton in Nottingham, Atake in Nagoya, Ishii in Tokojama, Valcárcel in La Coruña, Sánchez Cuenca in Gerona, and hundred more complete a list that it is sure will convert the mobility of structures in a new technology.

With so resumed relation of key achievements it is impossible to give an idea of how many possibilities we have to make architecture undetermined in the time and in the space. But in spite of it this intent could open to us an immense world of new possibilities. Till now only hyperstatic structures were accepted in our repertory. At this moment mechanisms are a new tool in the design.
REFERENCES

