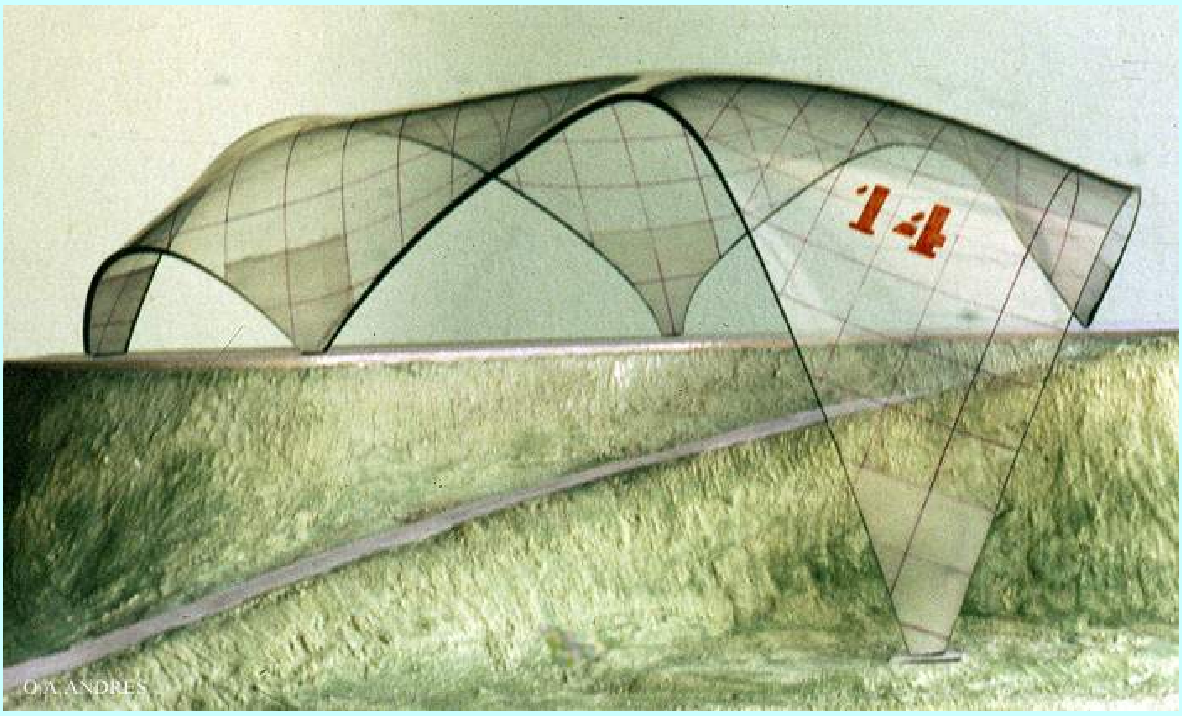
OSCAR A. ANDRES

PROFESOR CONSULTO UNS – PROFESOR PLENARIO UB

RECOPILACION DE TRABAJOS SOBRE EL TEMA

TEORIA Y TECNICA DE LOSMODELOS HOMEOSTATICOS



COLETTION OF PAPERS ON THE SUBJECT

THEORY AND TECHNIQUE OF HOMEOSTATIC MODELS

Segunda Parte (2006 – 2012)

Prologo de la Primera Parte

A MODO DE PROLOGO…

La creación de nuevas formas estructurales constituye un fascinante desafío que convoca por igual a ingenieros y arquitectos de nuestros días. La tarea resulta por demás atractiva e interesante cuando se piensa en las amplias posibilidades derivadas de los avances del Análisis Estructural como así también del uso de las nuevas Tecnologías de la Construcción. Encontrándome en la etapa de culminación de mi carrera docente y de investigación, debo reconocer que el tema de las formas estructurales cautivó mi atención y mis esfuerzos durante buena parte de mi vida. En efecto, algo más de tres décadas han transcurrido desde mi primera publicación en la materia. Dentro de ese lapso, ha sido la idea de los modelos homeostáticos – desarrollada a partir de 1987 – la que me deparó mayores satisfacciones. En esta recopilación he querido reunir una serie de trabajos dedicados exclusivamente a ese tema: Teoría y Técnica de los Modelos Homeostáticos. Al hacerlo así me anima un doble propósito:

En primer lugar, deseo agradecer y rendir mi homenaje a quienes me brindaron su apoyo y me ayudaron en esta tarea. En tal sentido, reitero mi gratitud y reconocimiento al Ing. Eladio Dieste sin cuya palabra de estímulo y aliento difícilmente mi idea hubiera transpuesto el umbral del Laboratorio; su valiosa y autorizada opinión templó mi espíritu y me nutrió con la fuerza necesaria para presentar esa idea no sólo en mi país, sino también en las más diversas latitudes. Vaya también mi sincero agradecimiento a mis más directos colabores quienes además de confiar y compartir mis ideas me acompañaron con su esfuerzo para desarrollarlas: R. E. Serralunga, N. F. Ortega, C. A. Schiratti y J. C. Paloto. Dejo también constancia de mi agradecimiento a Jorge Prado y Jessica Arias por la valiosa ayuda que me brindaron en la presentación de estos trabajos.

En segundo lugar, espero que esta publicación facilite el estudio de quienes, con una vocación similar a la mía e impulsados por el propósito de iniciarse o profundizare en el tema de las formas estructurales, procuren extender las fronteras del conocimiento mucho más allá de los modestos límites que yo traté de alcanzar.

Oscar A. Andrés

Bahía Blanca, Febrero 1999

Prologo de la Segunda Parte

A MODO DE PROLOGO …

En el año 1999 presenté una recopilación de mis trabajos de investigación desarrollados en el Laboratorio de Modelos Estructurales de la Universidad Nacional del Sur, bajo el título TEORÍA Y TÉCNICA DE LOS MODELOS HOMEOSTÁTICOS. Me animaba el propósito de hacer público mi reconocimiento a mis colaborares directos y dejar en ese compendio una tarea que facilite el estudio de quienes se sintieran motivados por el tema.

Claro está que cuando hice aquella publicación no pensaba que en el año 2012 me iba a encontrar con más trabajos para compartir con quienes sienten la vocación de buscar nuevas formas estructurales. Desde entonces a la fecha la Morfogénesis se ha constituido en una de las especialidades más dinámicas de la Ingeniería Estructural. Acompañando esa evolución y motivado por los resultados alcanzados continué produciendo nuevos trabajos que presento ahora con el mismo título: TEORÍA Y TÉCNICA DE LOS MODELOS HOMEOSTÁTICOS con el agregado SEGUNDA PARTE. Se mantiene la numeración correlativa con un total de 14 trabajos incluyendo el último "Innovation in the homeostatic model tchnique to generate free-forms" que fue aceptado recientemente para su presentación oral en el IASS Symposium of Seoul (South Korea).

Al publicar esta segunda recopilación me anima idénticos propósitos a los ya expresados en 1999 y confío que la Biblioteca será un fiel custodio de esta información para los estudiantes y graduados.

Oscar A. Andrés

Bahía Blanca, Mayo 2012

CONTENIDO

PRIMERA PARTE (desde 1988 a 1999, ver publicación anterior)

SEGUNDA PARTE (desde 2006 a 2012, en esta publicación)

Sub-working Group, Newsletter Nº 15, Delft University of Technology, The Netherlands, June 2008.

12- Andrés, O.A., The Homeostatic Model Its Conception and Development, IASS-SLTE, Symposium Shell and Spatial Structures, New Materials and Technologies, New Design and Innovations, México, 2008.

13- Andrés, O.A., About the Freedom of Free-Forms, IASS 50th Anniversary, Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures, Valencia, Spain, 2009

14- Andrés, O.A., Innovation in Homeostatic Model Technique to Generate Free-Forms, Symposium From Spatial Structures to Space, Structures, Seoul, South Korea , 2012.

Bahía Blanca, Mayo 2012.

En Biblioteca está disponible la versión PDF de esta publicación.

BREVE RESEÑA BIOGRÁFICA DEL AUTOR.

OSCAR A. ANDRÉS

Ingeniero Civil graduado en la UBA en 1952. Durante más de una década ejerció activamente la profesión compartiendo esta tarea con la docencia que años más tarde asumió en forma exclusiva.

El Diseño de Estructuras y la Enseñanza de la Ingeniería han sido los temas principales de su actividad desarrollada durante 59 años en la UNS como docente e investigador.

Fundador y Jefe del Laboratorio de Modelos Estructurales de la UNS donde concibió y desarrolló una técnica original para la generación de formas estructurales posteriormente presentada por el Prof. Mamoru Kawaguchi y reconocida como el método más avanzado para el diseño mediante modelos físicos en el congreso de la Asociación Internacional de Estructuras Laminares (IASS) celebrado en Francia en el año 2004.

Dio cursos y seminarios en Universidades del país y del exterior. Conferencista invitado en reuniones nacionales e internacionales de su especialidad.

Autor de trabajos publicados en el país y en el exterior. Uno de ellos fue distinguido con el Primer Premio en el concurso internacional auspiciado por el Consejo Superior de Investigaciones Científicas de España

Miembro Fundador de SAEI (Sociedad Argentina para la Enseñanza de la Ingeniería).

Socio vitalicio y Vicepresidente del Centro de Ingenieros de Bahía Blanca.

Miembro Permanente de la Asociación Argentina del Hormigón Pretensado.

En 1992 la UNS le otorgó el título de Profesor Consulto y en 1993 la UB (Universidad de Belgrano, Buenos Aires), el título de Profesor Plenario.

2006

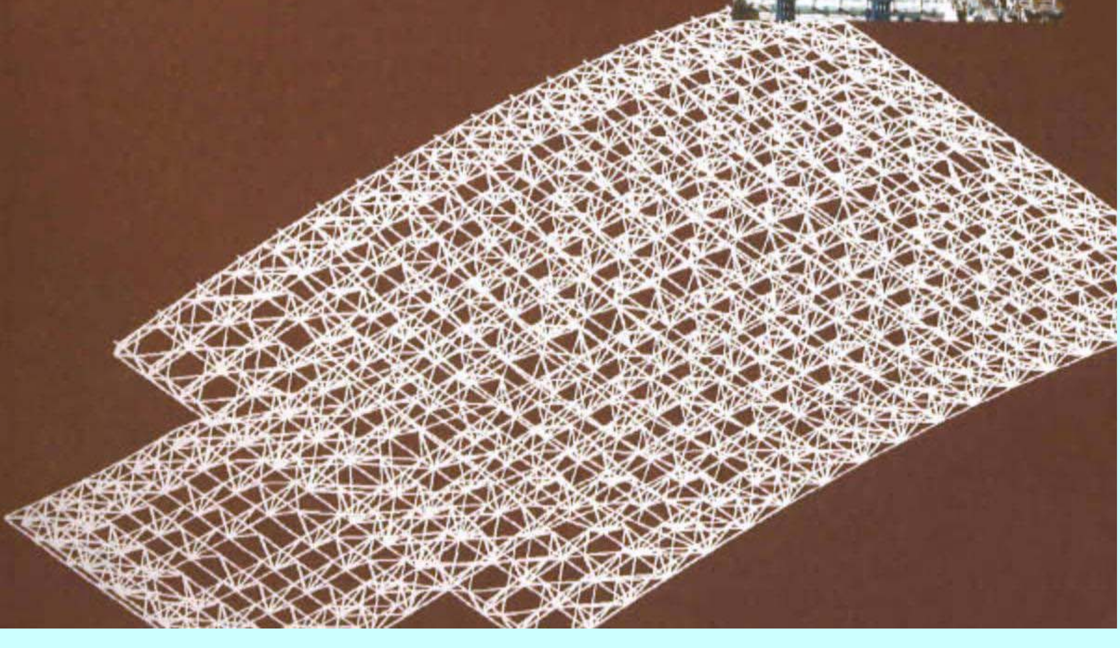
IASS-APCS 2006 BEIJING

IASS SYMPOSIUM

APCS CONFERENCE

NEW OLYMPICS

NEW SHELL AND SPATIAL STRUCTURES



HOMEOSTATIC MODELS: MORE THAN FORM-FINDING TOOLS

Oscar A. ANDRÉS
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ABSTRACT

Since very remote times models have played important roles in the art of construction. From the point of view of their functions, four types of model structures may be distinguished: *scale dimensional models, design models, analysis models* and *hybrid models.* Moreover there are sub-types as: physical and numerical models, preliminary and final models, permanent and ephemeral models. In this classification the Homeostatic Model falls into the category of "final physical permanent design model". It was created as a form-finding tool, i.e. to conceive, generate and determine the geometry of new structural shapes. Nowadays new applications have been developed for the homeostatic models. They can perform as hybrid models, wind models, experimental analysis models, teaching models, sculptural models. All of them are described and illustrated.-

1- INTRODUCTION

"The best investment in construction is the money devoted to scale models"
Michelangelo Buonarroti (1475-1564) [1]

Since very remote times, even centuries before the above words were said by Michelangelo, the famous genius of the Renaissance, models have played important roles in the art of construction. In the beginning, physical models were used to imagine the construction of buildings and structures, to check their resistance and to visualise their beauty. Today we have a great and complex variety of new types of models aiming at performing different functions. Models can be used to study buildings and structures. This paper deals with structural models only.

2- CLASSIFICATION OF STRUCTURAL MODELS TYPES

From the point of view of their functions, four types of model may be distinguished:

a) *Three dimensional scale models*: these are used to represent in 3D space existing structures or structures to be built
b) *Design models*: these are used to conceive and generate the design of a structure (It is assumed here the meaning of "conceptual design" for the word "design").
c) *Analysis models*: these are used to study the behaviour of a structure.
d) *Hybrid models*: these play both functions, design and analysis.

Some of the above mentioned types enclose two or more model sub-types: physical and numerical, preliminary and final, permanent and ephemeral models.

3- THE HOMEOSTATIC MODEL

In the above classification the Homeostatic Model (HM) falls into the category of "final physical permanent design model". It was created as a form-finding tool, i.e. to conceive, generate and determine the geometry of new structural shapes.

The HM was born in 1988 [2] when the author conceived it following the hanging inverted model technique introduced by the Italian scientist Giovanni Poleni (1683-1761) and improved later by the Catalonian architect Antoni Gaudí (1852-1926). Both of them used the funicular technique but aiming at different purposes: Poleni applied the funicular for the first time as an *analysis* model to study the stability of St. Peter's Dome of Rome, while Gaudí applied the same idea but as a *design* model to create new shapes, i.e. as a true form-finding tool. From this point of view Gaudí was indeed an authentic forerunner in the art of design

Previous papers of the author [3,4] have widely explained and illustrated the theory and technique of the HM. A brief description and comments on the HM are included in the following points.

3.1 Basic ideas

The basis of the HM is supported on Gaudí's philosophy which includes the "organic vital" conception of the structures as an essential idea [5].

The generation of the HM is obtained by adding up two actions on a thermoplastic plate:

a) load action (just the same as in the funicular model)
b) heat action

The introduction of the heat action is linked to the phenomenon known in Physiology as *homeostasis.* According to this principle every living creature tends to maintain its vital function when an external agent alters their balance. This phenomenon occurs automatically and following an intelligent plan which makes use of all the resources of the living creature before collapsing.

An analogous phenomenon occurs in a structure designed by man. Again, when this structure undergoes an aggression it makes an intelligent use of all its potential resources before collapsing. In the HM, load and heat are used as aggressive agents. Being the model built of thermoplastic material, the heat degrades its mechanical properties and homeostasis takes place. Intelligently the model changes its structural type and its form in order to resist as a membrane the load that cannot resist anymore as a plate. The structural model is obtained as the result of the reproduction of a natural phenomenon: the *homeostasis.*

3.2 Construction of Homeostatic Models

To build a model the following steps are carried out:

a) A plate is cut from a flat thermoplastic sheet. This plate is named "mother plate" because it will generate the model. (Fig. 1).
b) A loading carpet is applied on the mother plate.

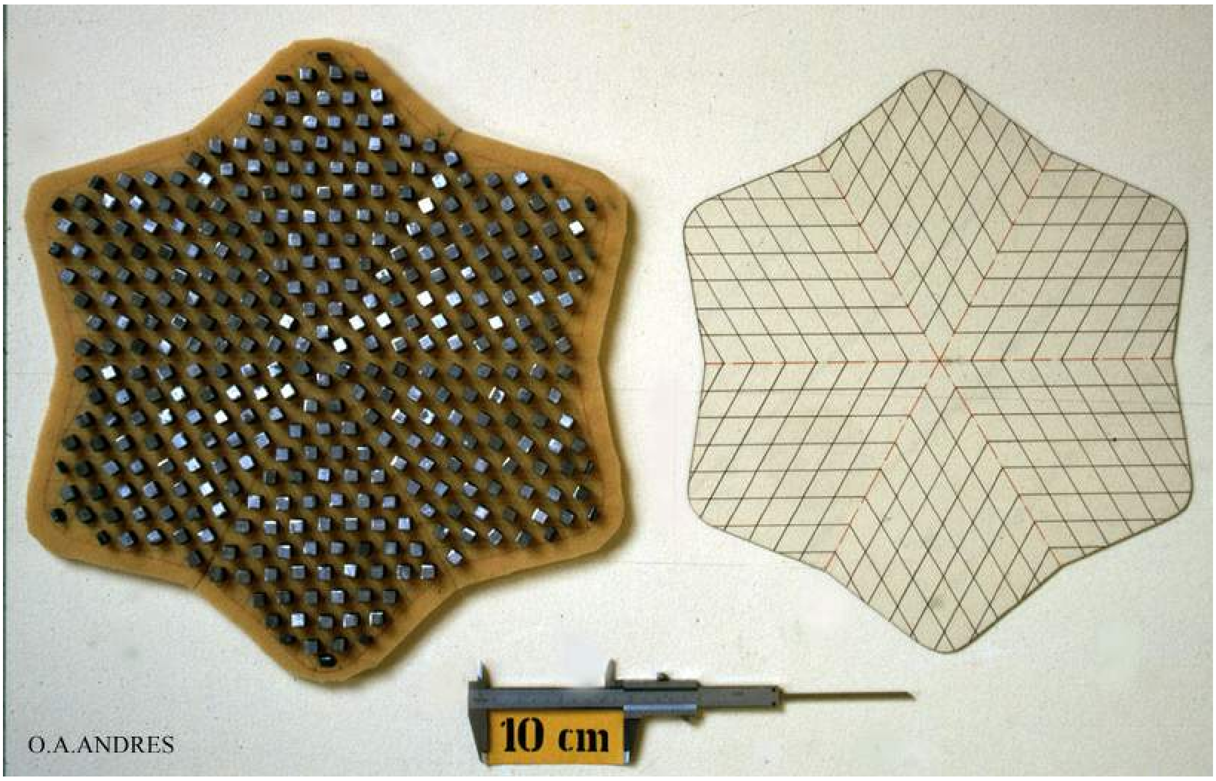

Fig 1. Loading carpet and mother plate

c) Mother plate, loading carpet and the corresponding balancing loads are introduced into an oven and heated until 120/130ºC. Due to the heat action on the thermoplastic plate, this material degrades its resistance and changes its shape and its structural type from plate to membrane to balance the load action.

Fig. 2. The mother plate to be heated in the oven.

Fig. 3. The model ready to leave the oven.

d) Once the model is cooled, its shape becomes rigid. Then it can be turned upside down and placed on its supports; now we have a shell structure model. (Fig. 2, 3, 4.)

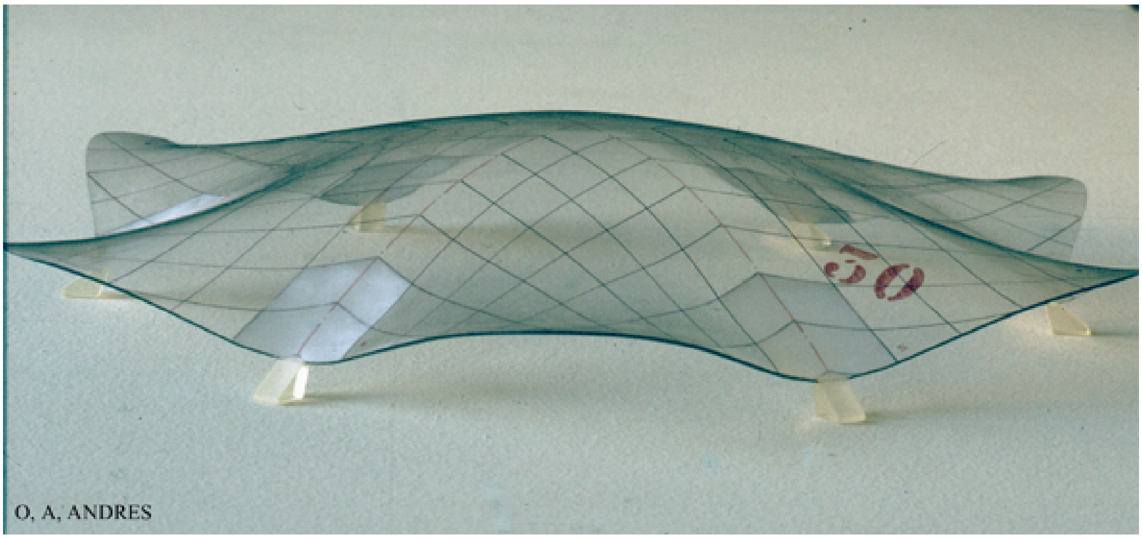

Fig. 4. The model after leaving the oven and mounted on its supports.

3.3 Main advantages and features of the HM.

a) Rigidity and smoothness of their surfaces allow a very precise measurement of model co-ordinates.
b) Easy and fast construction and consequently low cost construction.
c) Instead of ephemeral models, HMs are permanent models that can be handled for years.

d) In the HM technique there is space for both, freedom and automatism. In fact, freedom is present when the designer selects perimeter shape and edge conditions of the mother plate according to his criterion, while the automatism is present in the process once the model has been put in the oven.

e) The homeostatic model technique finds its most efficient and appropriated application in the field of free form shells supported on points and having free edges [6]. (Fig. 5, 6, 7, 8)

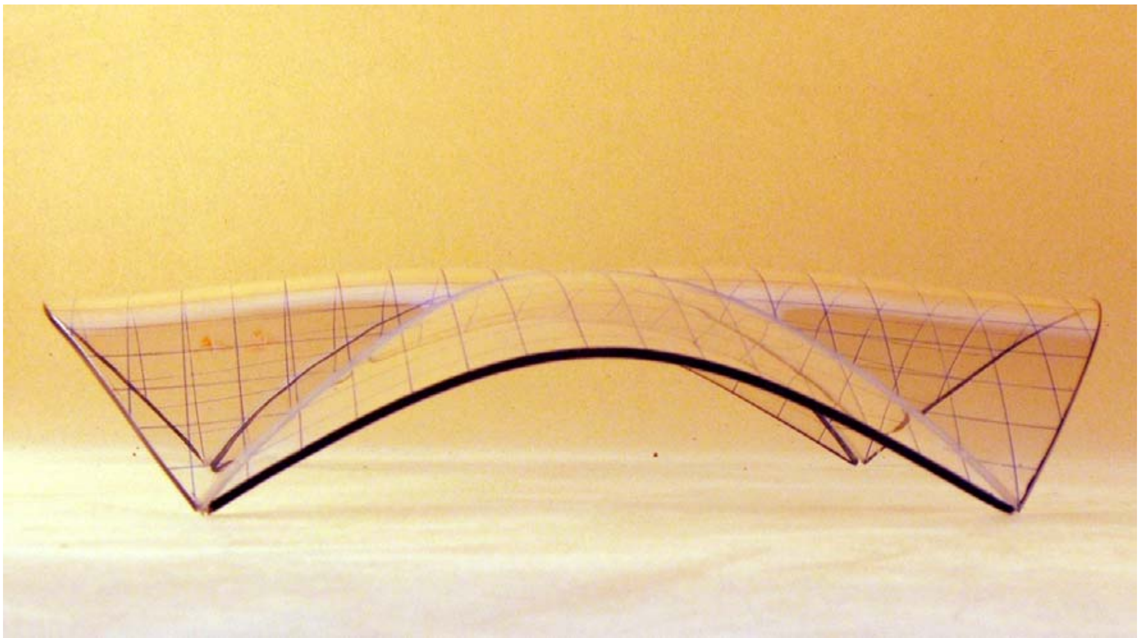

Fig. 5. Model shell roof supported on four points

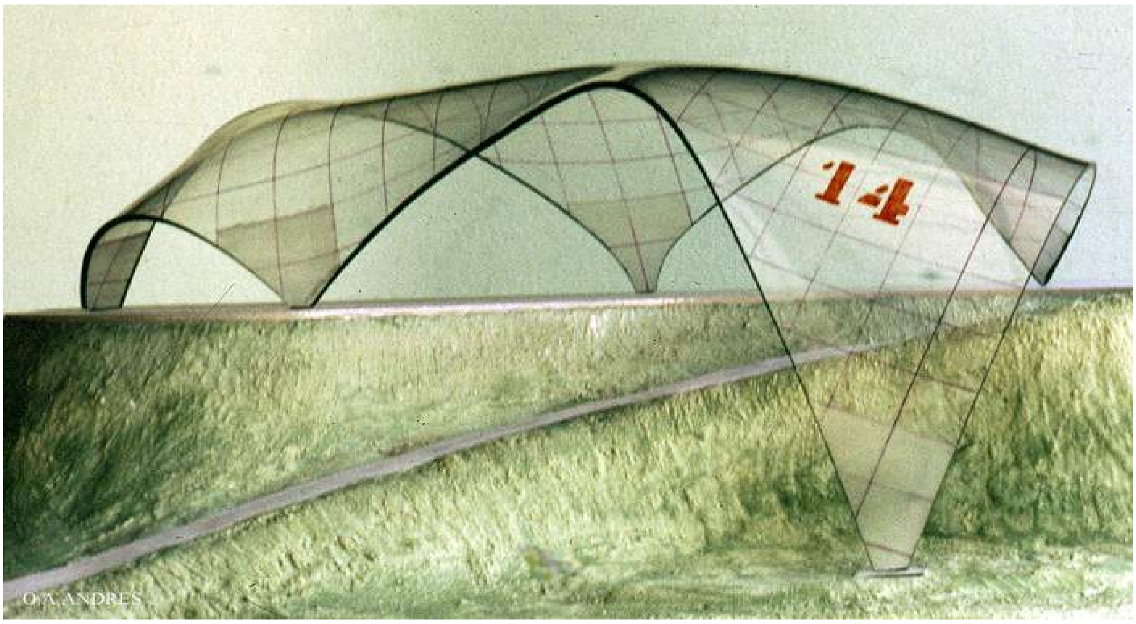

Fig. 6. Free shape model shell roof

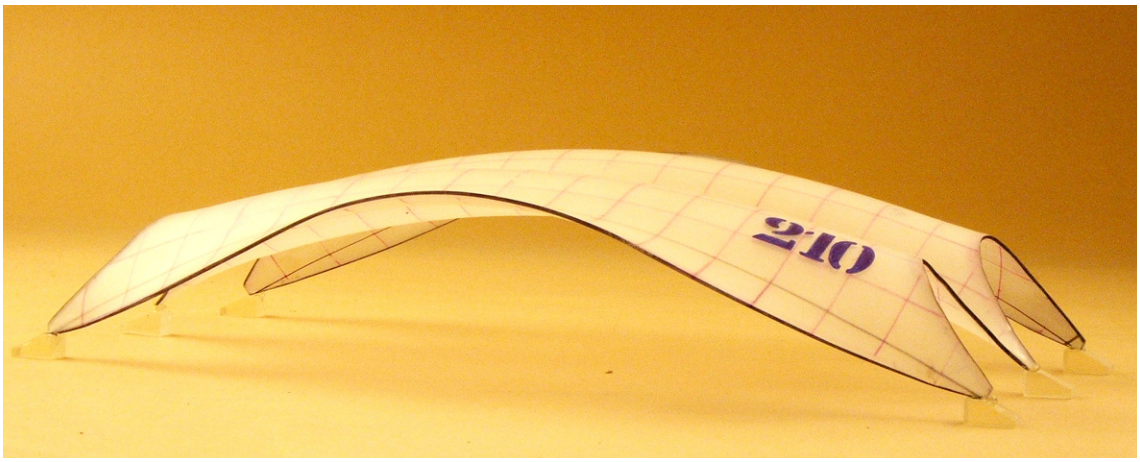

Fig. 7. Model shell roof supported on six points

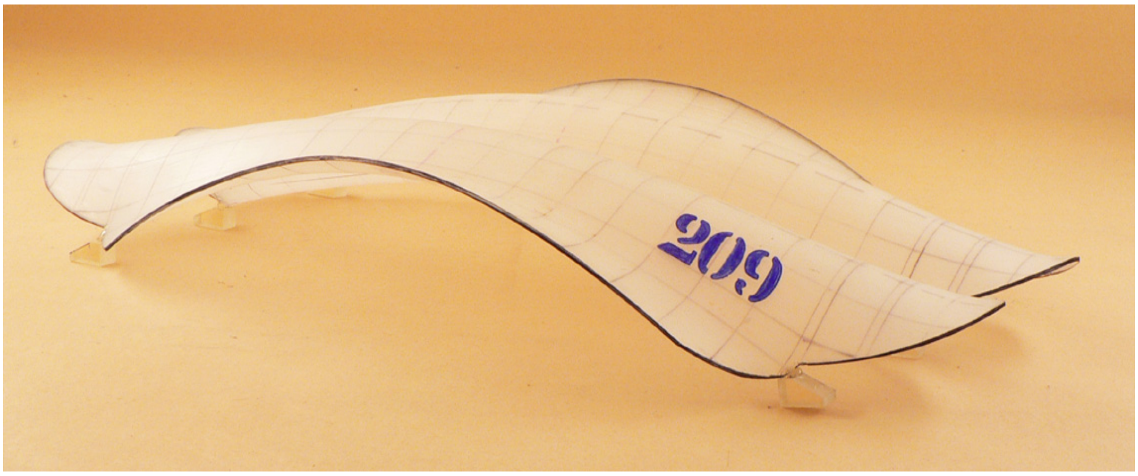

Fig. 8. Model shell roof with eaves supported on six points

4- BEYOND THE HOMEOSTATIC MODEL: ITS EVOLUTION.

Since 1988 when the author applied the principle of homeostasis for the first time, he and his collaborators have been working to improve and develop new applications of the HM. Some of the main achievements are reviewed in the following points.

4.1 The total model (hybrid model)

Once the structural architect/engineer has designed a structure he must analyse it in order to verify its behaviour. To perform both functions (design and analysis) in only one tool, a hybrid model named "the total model" was developed. In fact, as it has been told, the HM has a particular feature: its surface is perfectly smooth and remains stable under the pressure of an electronic touch probe, then co-ordinates of its points can be exactly measured by means of a 3D digital scanner (SpaceArm); this device gives a complete file of all the co-ordinates. By this way the physical model is turned into a numerical model. Then the analysis can be performed by any structural software [7]. (Fig. 9)

4.2 Wind models.

HMs made by the author were tested in a wind tunnel of the Facultad de Ingeniería, UNNE (Resistencia, Chaco, Argentina). The models were set in the tunnel and allowed the measurement of wind pressures just the same as conventional wind models. Test results were reliable and from the aerodynamic viewpoint the models performed quite well [8]. (Fig. 10).

Fig. 9. Scanning the model by the SpaceArm.

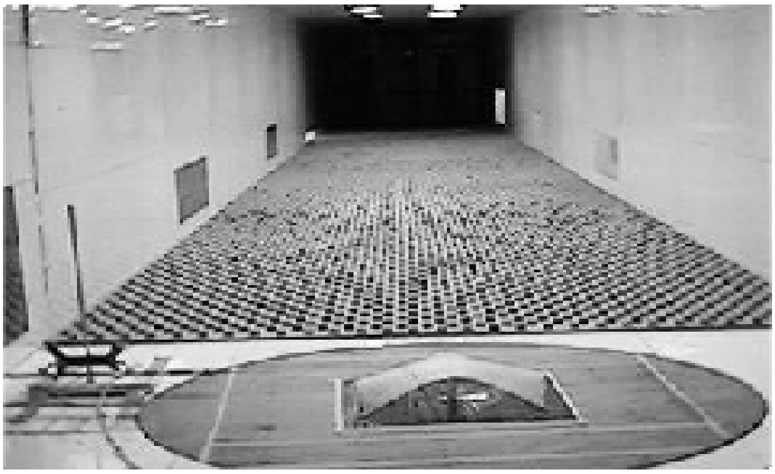

Fig. 10. Testing the model in the wind tunnel

4.3 Experimental analysis models.

Several HMs were used to perform strain analysis by means of electrical strain gauges. Deflections under loads were also measured through mechanical gauges. In this way, comparison with numerical models was carried out successfully [7].

Fig. 11. Feeling the strength by shape: plate vs. shell

4.4 Teaching models.
The handling of the HM, as any physical model, gives the feeling of strength and space immediately. Students can, for example, understand quickly the concept of resistance by shape as well as appreciate the aesthetics of the forms. [9] (Fig.11)

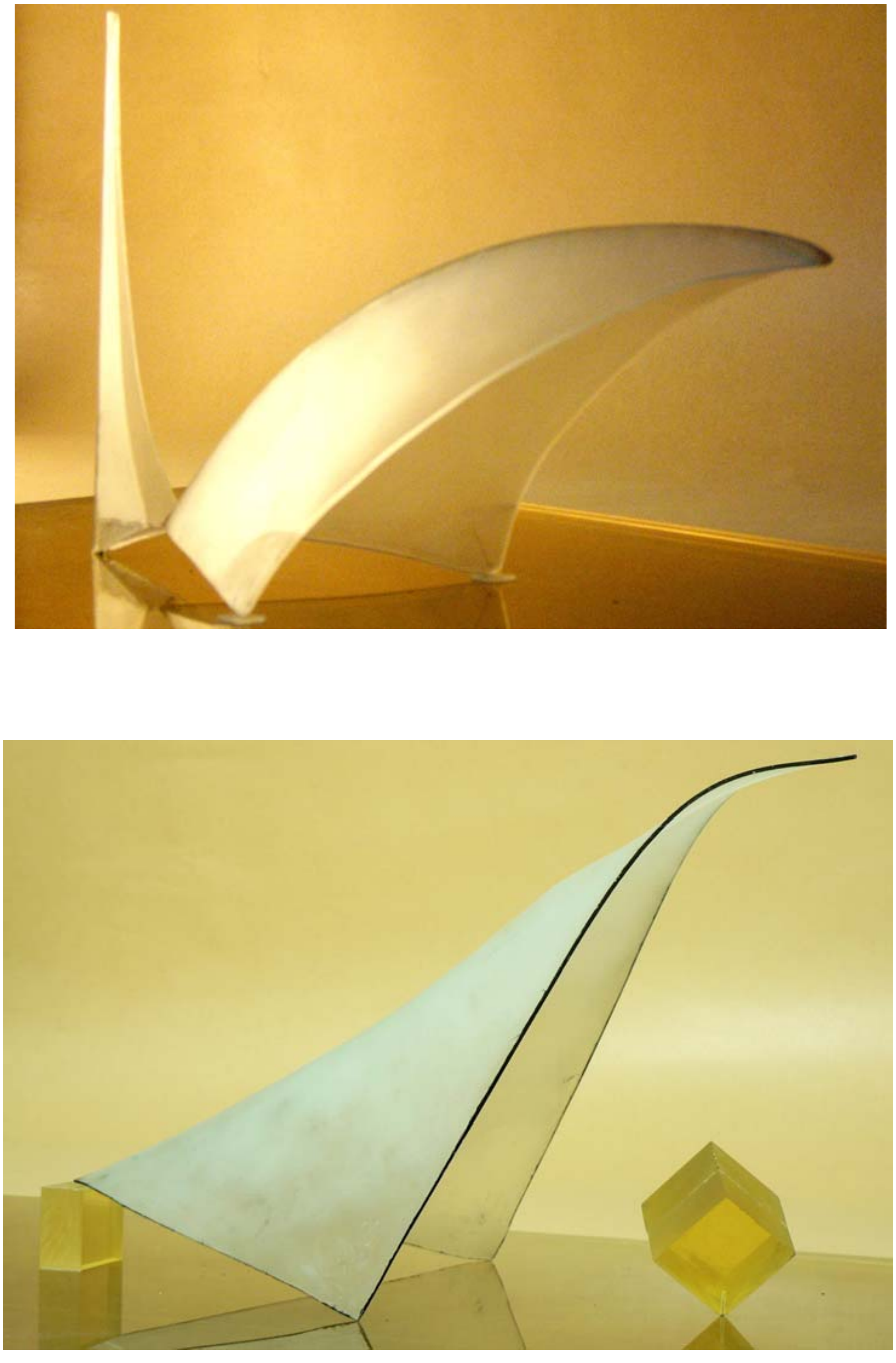

Fig. 12. Two sculptural homeostatic models.

4.5 Sculptural models.
The HMs are not only valued as structural pieces, but they also exhibit their own aesthetic value as beautiful objects. Being the expression of Nature's laws (gravity and homeostasis) they have a logical and permanent beauty independently from temporary aesthetic trends [10]. (Fig. 12)

5- FINAL REFLECTION.

Beyond the innovations introduced from the technical viewpoint, the author thinks that the real and remarkable value of the HM must be found in the introduction of the *principle of the homeostasis* into the field of the Structural Mechanics. New roads are open to study the behaviour of structures: instead of the conventional structural analysis through the action of increasing loads, alternative ways should be tried. One of them is performed by degrading the material through the action of heat, for example, as it has been done in the HM. To go deep into these new roads could be an interesting challenge for the younger researchers.

ACKNOWLEDGEMENT.
The author is grateful to the technician Juan Pablo Gorordo for his meritorious assistance in making models and photographs in the Laboratorio de Modelos Estructurales, Departamento de Ingeniería, Universidad Nacional del Sur.

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THE HOMEOSTATIC MODEL: ITS CONCEPTION AND DEVELOPMENT

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[2]*Professor, Universidad Nacional del Sur, Bahía Blanca, Argentina*
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ABSTRACT

Since very remote times models have played important roles in the art of construction. From the point of view of their functions, four types of model structures may be distinguished: *three dimensional scale models, design models, analysis models* and *hybrid models.* Moreover there are sub-types as: physical and virtual models, preliminary and final models, permanent and ephemeral models. In this classification the Homeostatic Model falls into the category of "final physical permanent design model". It was created as a form-finding tool, i.e. to conceive, generate and determine the geometry of new structural forms. Nowadays new applications have been developed for the homeostatic models. They can perform as hybrid models, wind models, experimental analysis models, teaching models, sculptural models. All of them are described and illustrated.

KEYWORDS

Models, homeostatic model, hybrid model, free form, teaching model.

1- INTRODUCTION

"The best investment in construction is the money devoted to models"
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Since very remote times, even centuries before the above words were said by Michelangelo, the famous genius of the Renaissance, models have played important roles in the art of construction. In the beginning, physical models were used to imagine the construction of buildings and structures, to check their resistance and to visualise their beauty. Today we have a great and complex variety of new types of models aiming at performing different functions. Models can be used to study buildings and structures. This paper deals with structural models only.

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Previous papers of the authors [3, 4] have widely explained and illustrated the theory and technique of the HM. A brief description and comments on the HM are included in the following points.

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The generation of the HM is obtained by adding up two actions on a thermoplastic plate:
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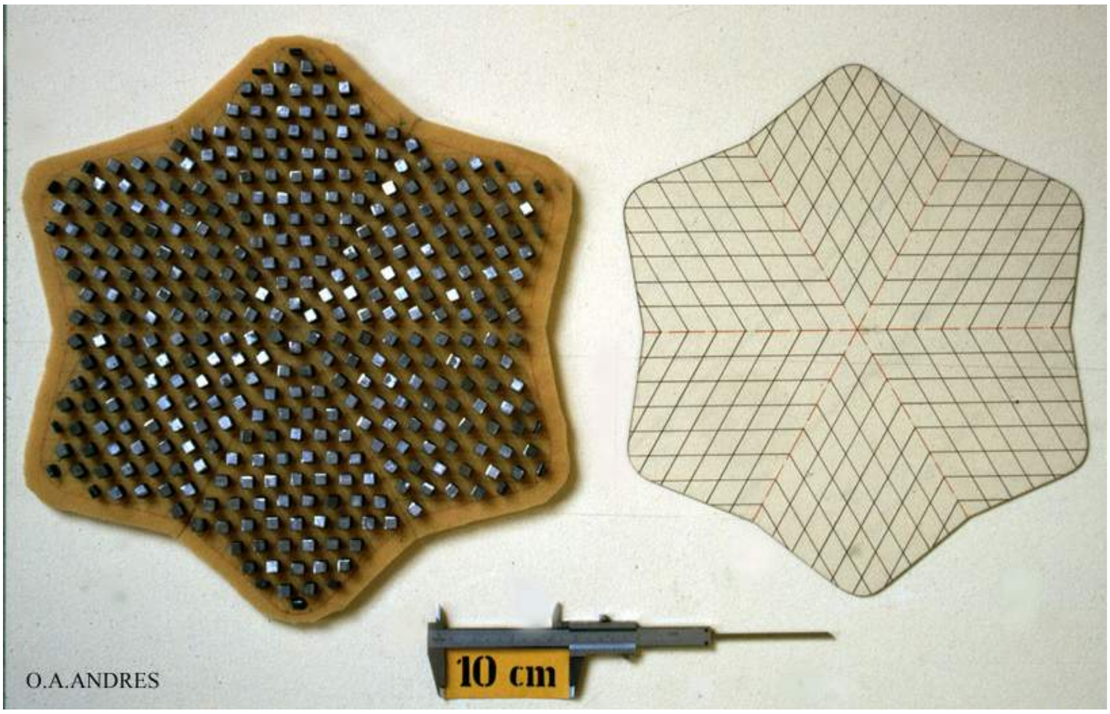

Fig 1. Loading carpet and mother plate

c) The plate, loading carpet and the corresponding balancing loads are introduced into an oven and heated until 120/130ºC. Due to the heat action on the thermoplastic plate, this material degrades its resistance and changes its form and its structural type from plate to membrane to balance the load action.

Fig. 2. The mother plate to be heated in the oven.

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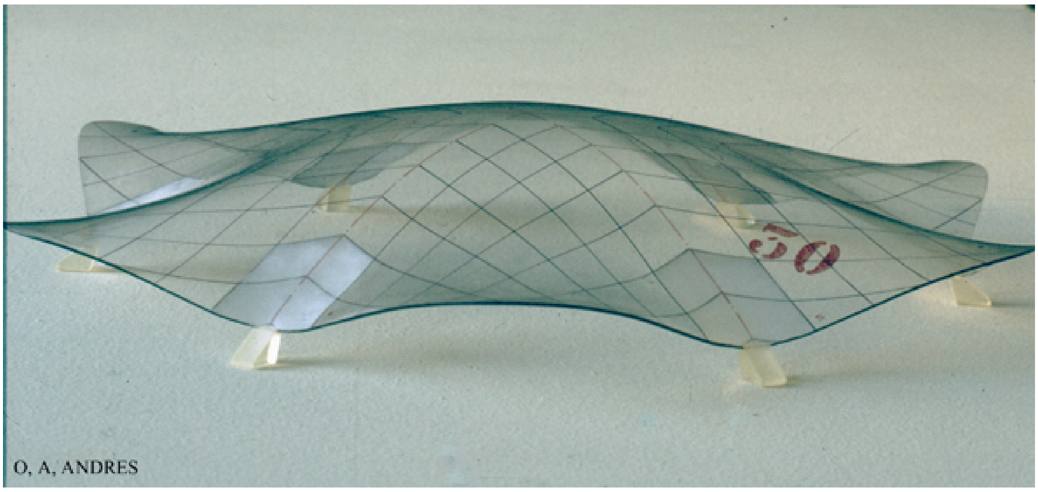

Fig. 4. The model after leaving the oven and mounted on its supports.

d) Once the model is cooled, its form becomes rigid. Then it can be turned upside down and placed on its supports; now we have a homeostatic shell structure model. (Fig. 2, 3, 4.)

3.3 Main advantages and features of the HM.

Following are listed the main advantages and features of the HM:

a) The rigidity and smoothness of their surfaces allow a very precise measurement of model co-ordinates.
b) Easy and fast construction and consequently low cost construction.
c) Instead of ephemeral models, HMs are permanent models that can be handled for years.
d) In the HM technique there is space for both, freedom and automatism. In fact, freedom is present when the designer selects perimeter shape and edge conditions of the mother plate according to his own criterion, while the automatism is present in the process once the model has been put in the oven.
e) The homeostatic model technique finds its most efficient and appropriated application in the field of *free form* shells supported on points and having free edges [6]. (Fig. 5, 6, 7, 8, 9).

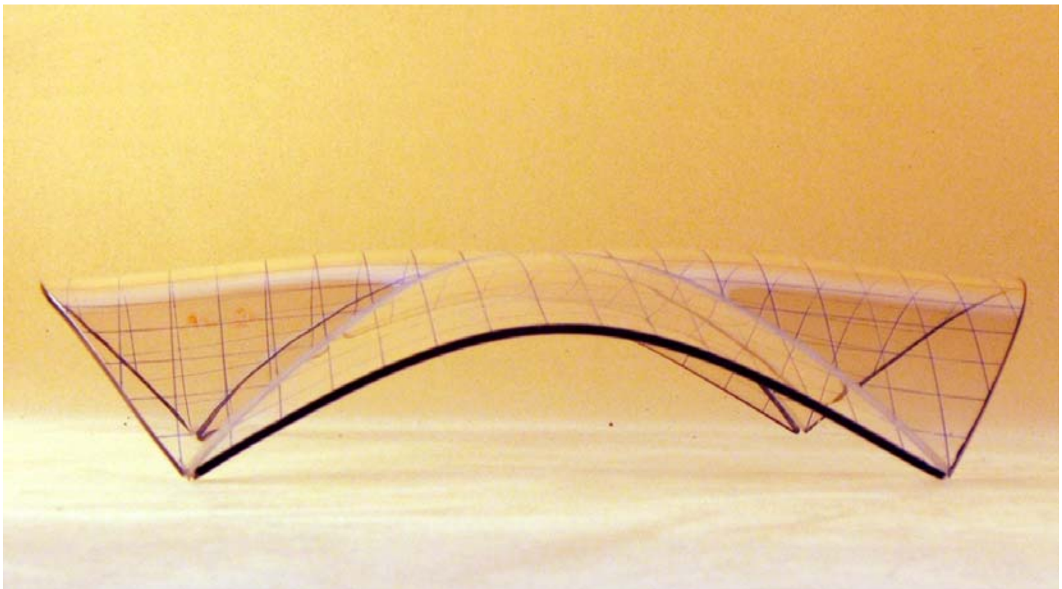

Fig. 5. Model shell roof supported on four points

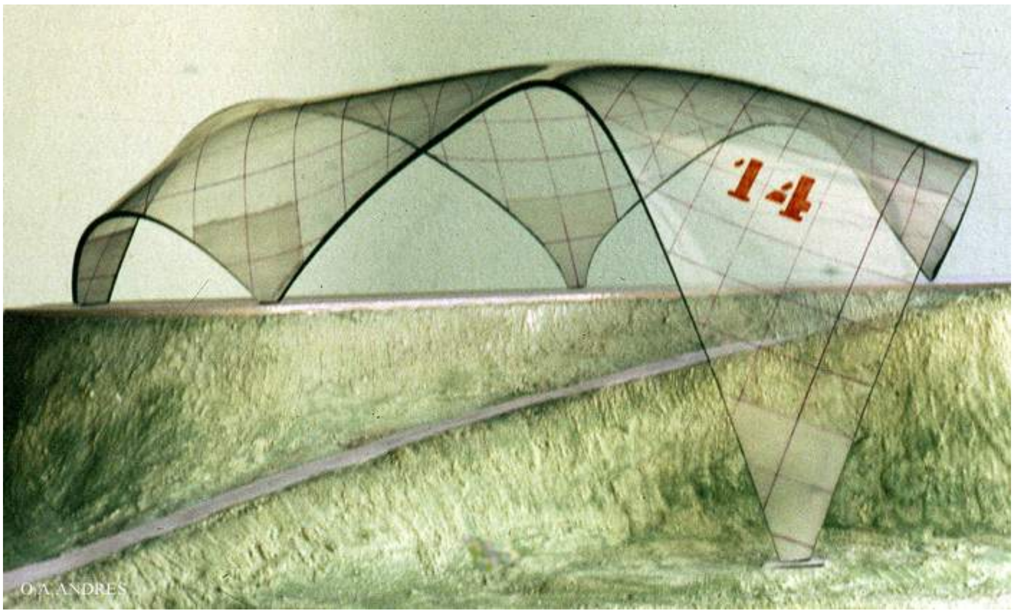

Fig. 6. Free form model shell roof

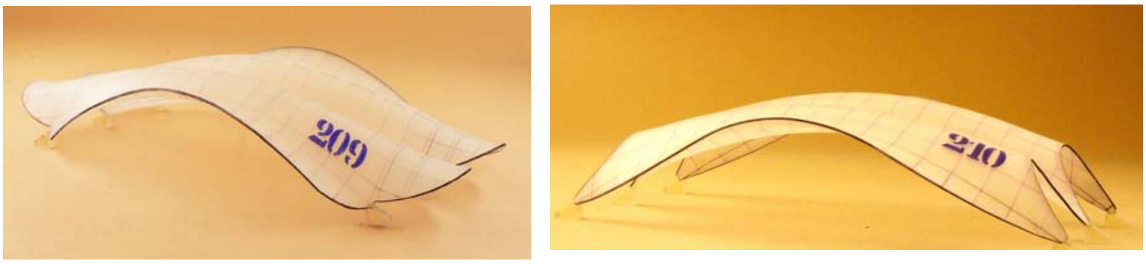

Fig. 7. Shell roof models supported on six points

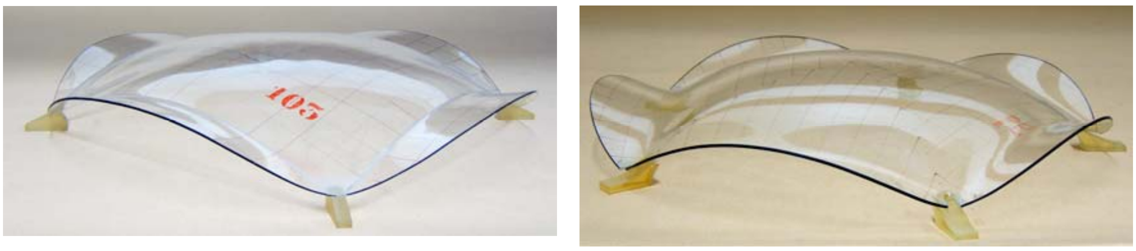

Fig. 8. Shell roof models supported on four and five points

4- BEYOND THE HOMEOSTATIC MODEL: ITS DEVELOPMENT.

Since 1988 when O. Andrés applied the principle of homeostasis for the first time, he and his collaborators have been working to improve and develop new applications of the HM. Some of the main achievements are reviewed in the following points.

4.1 The total model (hybrid model)

Once the structural architect/engineer has designed a structure he must analyse it in order to verify its behaviour. To perform both functions (design and analysis) in only one tool, a hybrid model named "the total model" was developed. In fact, as it has been told, the HM has a particular feature: its surface is perfectly smooth and remains stable under the pressure of an electronic touch probe, then the co-ordinates of its points can be exactly measured by means of a 3D digital scanner (SpaceArm); this device gives a complete file of all the co-ordinates. By this way the physical model is turned into a virtual model. Then the analysis can be performed by any structural software [7]. (Fig. 10)

Fig.10. Scanning the model by the SpaceArm.

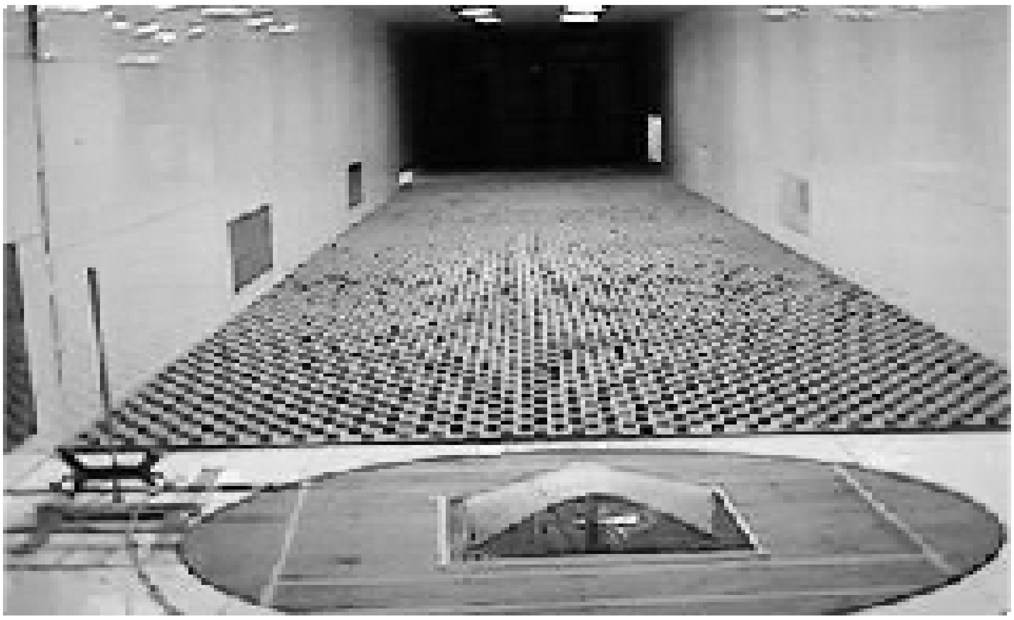

Fig. 11. Testing the model in the wind tunnel

4.2 Wind models.

HMs made by the authors were tested in a wind tunnel of the Facultad de Ingeniería, UNNE (Resistencia, Chaco, Argentina). The models were set in the tunnel and allowed the measurement of wind pressures just the same as conventional wind models. Test results were reliable and the models performed quite well from the aerodynamic viewpoint [8]. (Fig. 11).

4.3 Experimental analysis models.

Several HMs were used to perform strain analysis by means of electrical strain gauges. Deflections under loads were also measured through mechanical gauges. In this way, comparison with virtual models was carried out successfully [7].

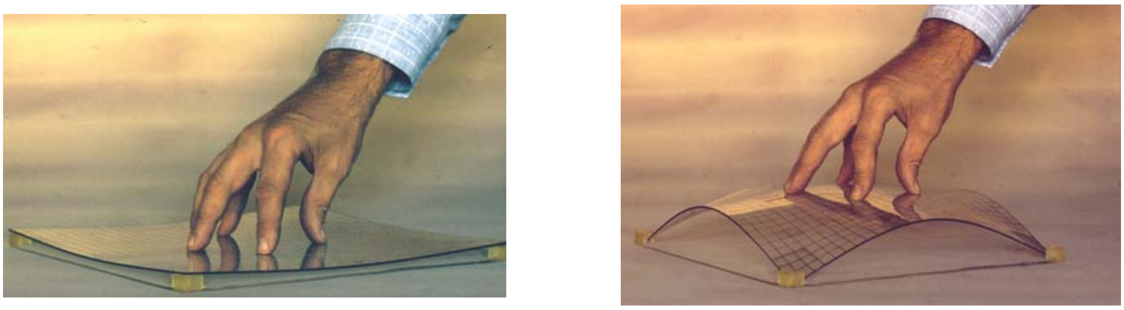

Fig. 12. Feeling the strength by shape: plate vs. shell

4.4 Teaching models.

The handling of the HM, as any physical model, gives the feeling of strength and space immediately. Students can, for example, understand quickly the concept of resistance by shape as well as appreciate the aesthetics of the forms. [9] (Fig.12)

Fig.13. Sculptural homeostatic model

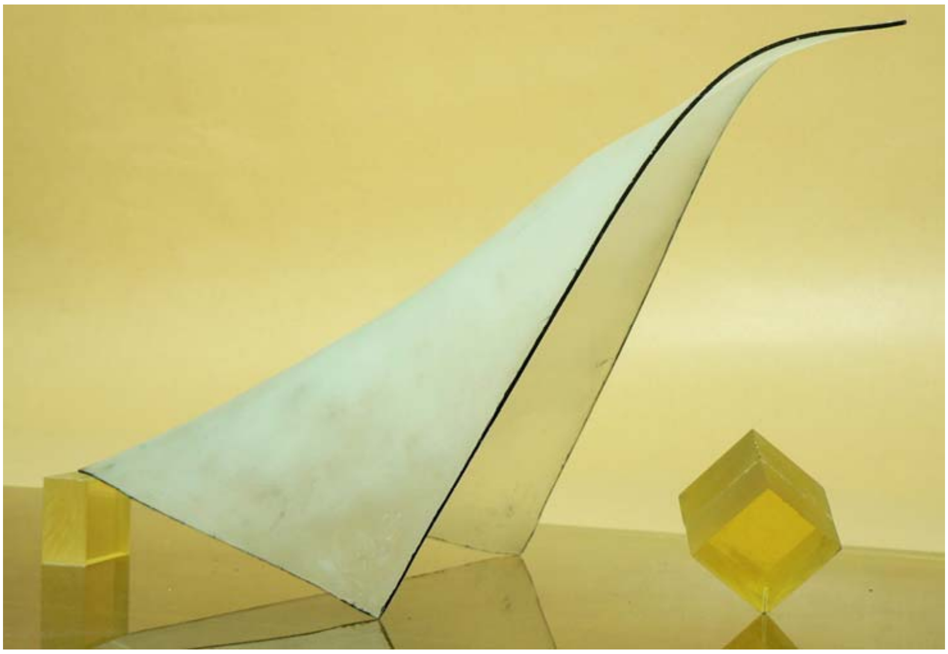

Fig. 14 Sculptural homeostatic model.

4.5 Sculptural models.

The HMs are not only valued as structural pieces, but they also exhibit their own aesthetic value as beautiful objects. Being the expression of Nature's laws (gravity and homeostasis) they have a logical and permanent beauty independently from temporary aesthetic trends [10, 11]. (Fig. 13, 14)

5- FINAL REFLECTION.

Beyond the innovations introduced from the technical viewpoint, the authors think that the real and remarkable value of the HM must be found in the introduction of the *principle of the homeostasis* into the field of the Structural Mechanics. New roads are open to study the behaviour of structures: instead of the conventional structural analysis through the action of increasing loads, alternative ways should be tried. One of them is performed by degrading the material through the action of heat, for example, as it has been done in the HM. To go deep into these new roads could be an interesting challenge for the younger researchers.

ACKNOWLEDGEMENT.

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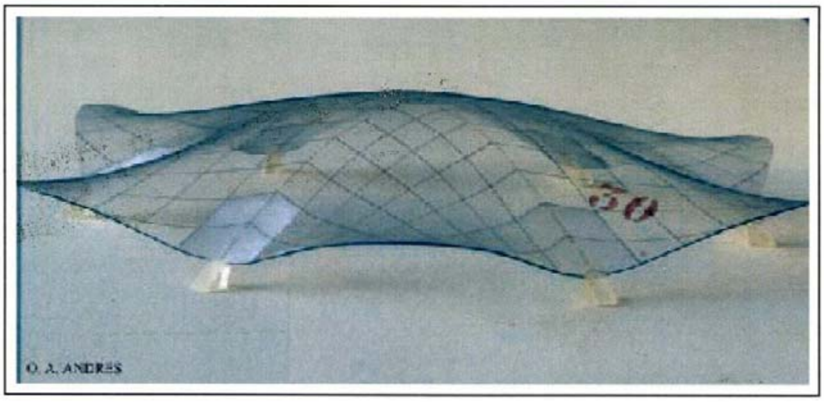

Structural Morphology Group
IASS Working Group N°15

Free-Form Design
IASS Sub-working Group

THE HOMEOSTATIC MODEL TECHNIQUE AND THE FREE-FORM DESIGN

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1- Introduction

The main purpose of this article is to present the HMT (Homeostatic Model Technique) and its application to design free-form shell roofs. The HMT is an experimental technique which allows the designer to generate the structural shape by means of physical models made of plastic through the action of heat and loads. The author presented this technique for the first time in 1988 and since then he has explained its philosophy, applications and developments in numerous publications [see References]. Following the basic principles are summarized, the construction of the models is described, and advantages and developments of the HMT are reported.

2- Basic principles

The HMT is inspired on Gaudí's philosophy together with the funicular technique and it is based on the physiological principle known as *homeostasis*.

Two are the main points of Gaudí's philosophy: a) reverential respect to Nature's laws, and b) understanding the behavior of structures like if they were living creatures. Regarding his funicular technique, he used the funicular model to design the best shape for compression structures (arches, ribs, etc) built with bricks or stones. (The funicular model was a hanging thread submitted to the action of loads). This technique works perfectly when applied on plane structures but it does not work on spatial structure like shell roof which are built nowadays.

Let's see now the *homeostasis*. In accordance with this principle, all living creatures tend to reestablish the balance of their vital functions when any external agent (homeostatic agent) alters such balance. This phenomenon occurs automatically and is ruled by an intelligent plan which puts in action all the potential resources of the creatures before their collapse. An analogous phenomenon takes place in the structures designed and built by man. Let's imagine for example, a small square plate of thermoplastic (an acrylic sheet 2 mm thick, 400 mm side) hanging from its corners and under the action of a uniformly distributed load on its surface. The equilibrium among the loads and the resistant forces will be altered when heat is applied as homeostatic agent. In fact, heat will degrade the mechanical properties of the thermoplastic material and then the plate will automatically develop an intelligent plan activating its whole potentiality before collapsing. The structures will metamorphose looking for a new position of equilibrium. In this homeostatic evolution, the plate will change not only its shape but also its structural type becoming a membrane when the equilibrium has been attained.

The so formed membrane is a homeostatic model. Its middle surface represents the "thrust surface" for the designing load, i.e. for the load applied to the model. Such a model can be used directly to become a hanging structure or it can be reversed to become a supported one. Since the model was formed when the thermoplastic material had a very low (or negligible) bending stiffness, due to the heat action, it will have a minimal bending behavior for the designing load.

From the conceptual viewpoint the HMT can be seen as an extension of Gaudí's funicular technique. While the funicular threads models apply to plane structures and discontinued space structures, homeostatic models apply to continuous space structures.

3- Application: design of a free-form shell structure

The HMT offers very interesting possibilities and a wide perspective of development when it is utilized for the design of free-form shell structures. To illustrate this point of view an application will be described. The applied methodology can be summarized in the following steps:

a. Having in mind the functional requirements of the building to be designed, the perimeter shape and the supported points are determined.

b. A plate is cut from a thermoplastic sheet in accordance with that perimeter (This plate is called "mother plate" because it will generate the model).

c. A "loading carpet" is made of small pieces which are stuck on a polyester sheet. It represents the predominant uniform load of about 1, 5 kN/m^2. (Fig. 1).

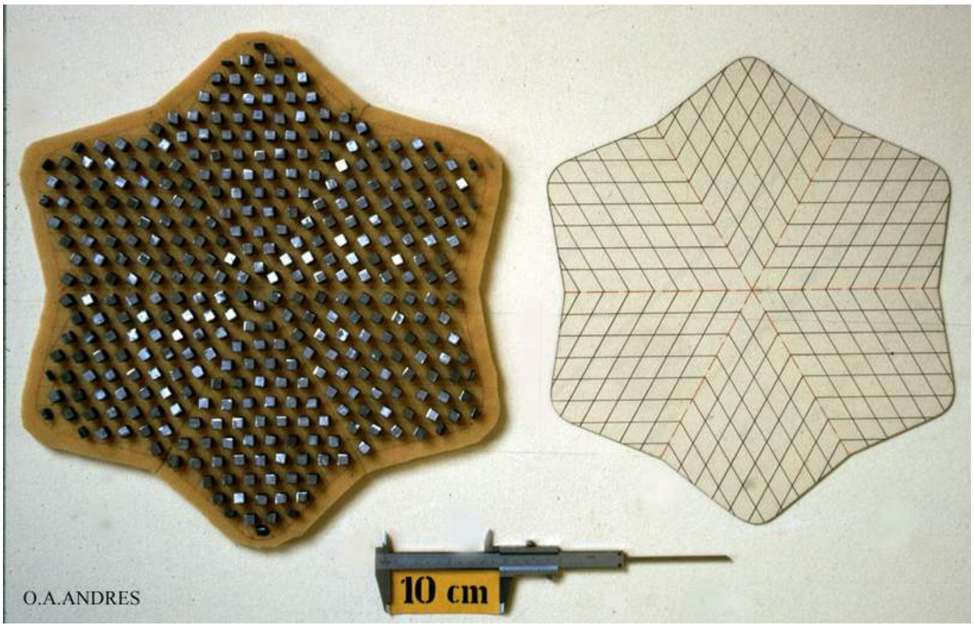

Fig.1 Loading carpet and mother plate

d. The plate is suspended from the points representing the supports and then, the loading carpet is applied over it.

e. By mean of pulleys and threads, weights representing the reactions are linked to the supports to balance the loading carpet.

f. The assembly (plate, load, pulleys and balance weights) is put into an oven and its temperature is increased up to 120/130ºC during three or four hours and then the heat input is switched off. (Fig. 2,3).

g. Once the model has cooled down to room temperature the thermoplastic material recovers its original stiffness but keeps its homeostatic form. (Fig. 4).

h. Coordinates of the model can be now easily measured and translated through the corresponding scale into the building structure.

It must be pointed out that the homeostatic evolution generates a predominantly tension structural type. By simple inverting the shape thus obtained it will be possible to pass to a predominantly compression structural type.

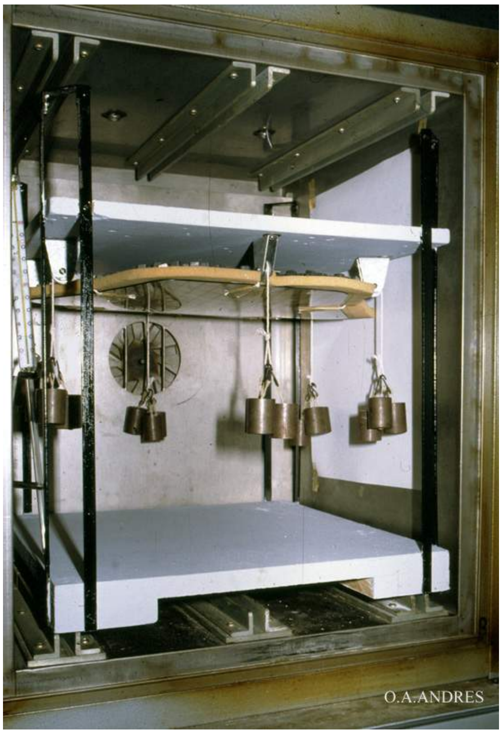

Fig. 2 The mother plate in the oven.

Fig. 3 The model ready to leave the oven.

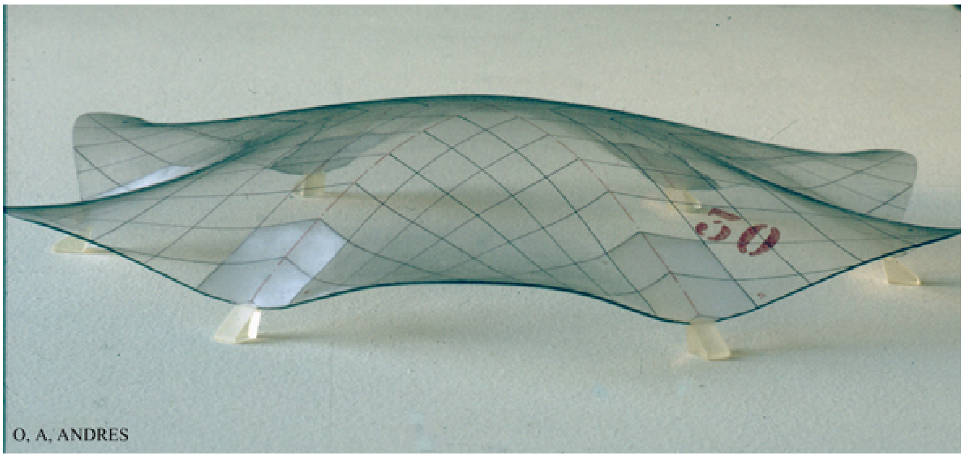

Fig. 4 The model mounted on its supporting points

Different free-forms obtained through the HMT are shown in Fig. 5. They have free edges and are supported on points.

4- Main advantages.

Following are listed some advantages of the HMT:

1. Models are steady and permanent trough the time, not ephemeral such as other model types are. The stiffness of the models is very high (as related to the stiffness of the mother plate) and being their surfaces quite smooth, their geometric coordinates can be measured very easily and with high accuracy.

2. The stiffness of the models is very high (as related to the stiffness of the mother plate) and being their surfaces quite smooth, their geometric coordinates can be measured very easily and with high accuracy.

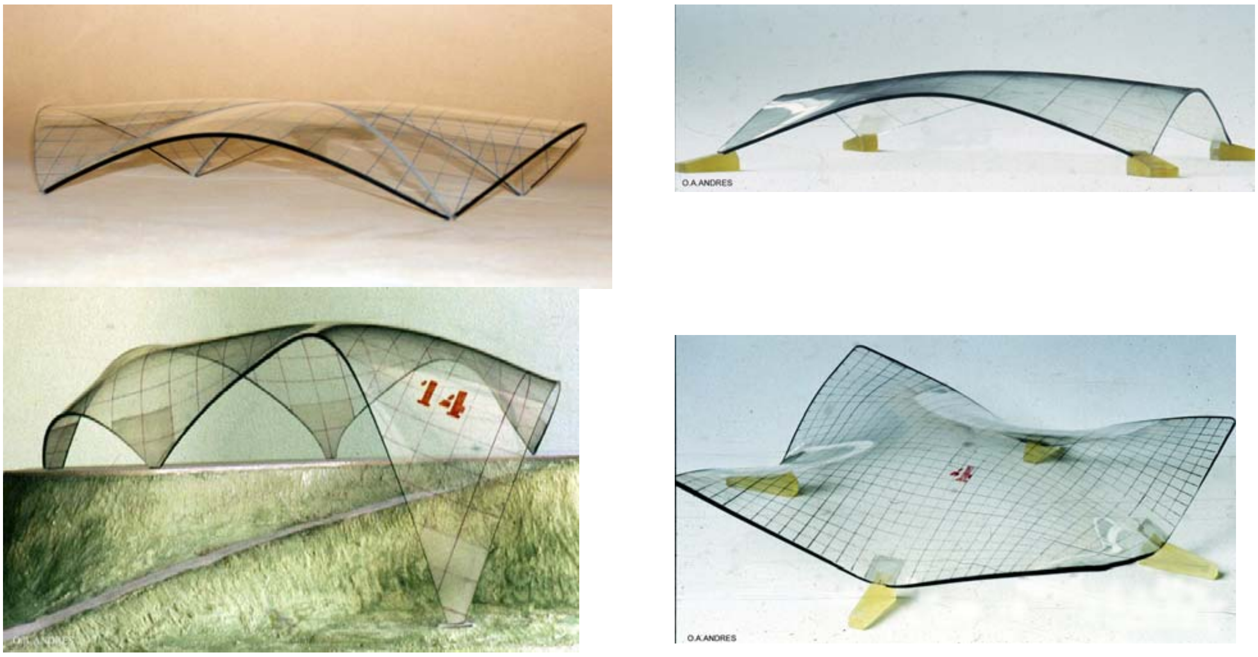

Fig. 6 Some free-form model obtained through HMT.

3. The most appropriated field for the application of the HMT is the design of free-form structures. In fact, in this case the designer needs and he reaches complete freedom to operate with the incident factors on his task (such as the shape of the perimeter plan, type and number of supporting points, their position and direction, slopes and depth of the shell, etc) but having always in mind and <u>respecting automatically the laws of equilibrium</u>. Moreover the resulting shapes work in quasi membrane state and so they have optimal structural behavior.

4. The construction and handling of the homeostatic models become highly stimulating for the designer creativeness; professionals and students appreciate immediately this point.

5. The construction of the models is a simple, rapid and low cost task.

5- New developments.

Although the HMT was originally conceived as a form-finding tool, new applications and functions have been developed:

1. *Analysis models*: models obtained by the HMT have been used directly to apply the well known techniques of experimental stress analysis. Through electrical gauges, strains and deflections have been measured successfully.

2. *Total models*: to perform a double function (design and analysis) by means of only one tool, a hybrid or total model was developed. Through a 3D digital scanner (SpaceArm) the geometric coordinates of the surface points are measured and saved in virtual files. By this way the original physical model is turned into a numerical model. Then analysis can be performed by any structural software. (Fig, 7).

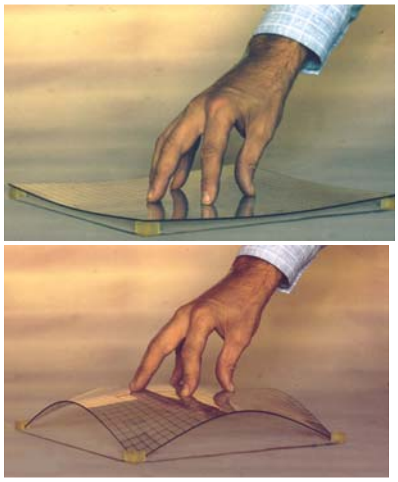

Fig. 6 Scanning the model Fig. 7 Feeling the strength by shape

3. *Wind models*: homeostatic models were set in wind tunnel and allowed the measurement of wind pressures just the same as conventional wind models.

4. *Teaching models*: the handling of the homeostatic models gives the feeling of strength and space immediately. Students can, for example, understand quickly the concept of strength by shape as well as appreciate the aesthetics of the forms. (Fig. 7)

6- Future researches.

Moreover minor innovation like the loading carpet and the degradation of material proprieties by means of heat, the most significant innovation of the HMT has been the introduction of the principle of the homeostasis in the field of the Structural Mechanics. To explore and advance in this new road could be an interesting challenge, mainly for the young researches.

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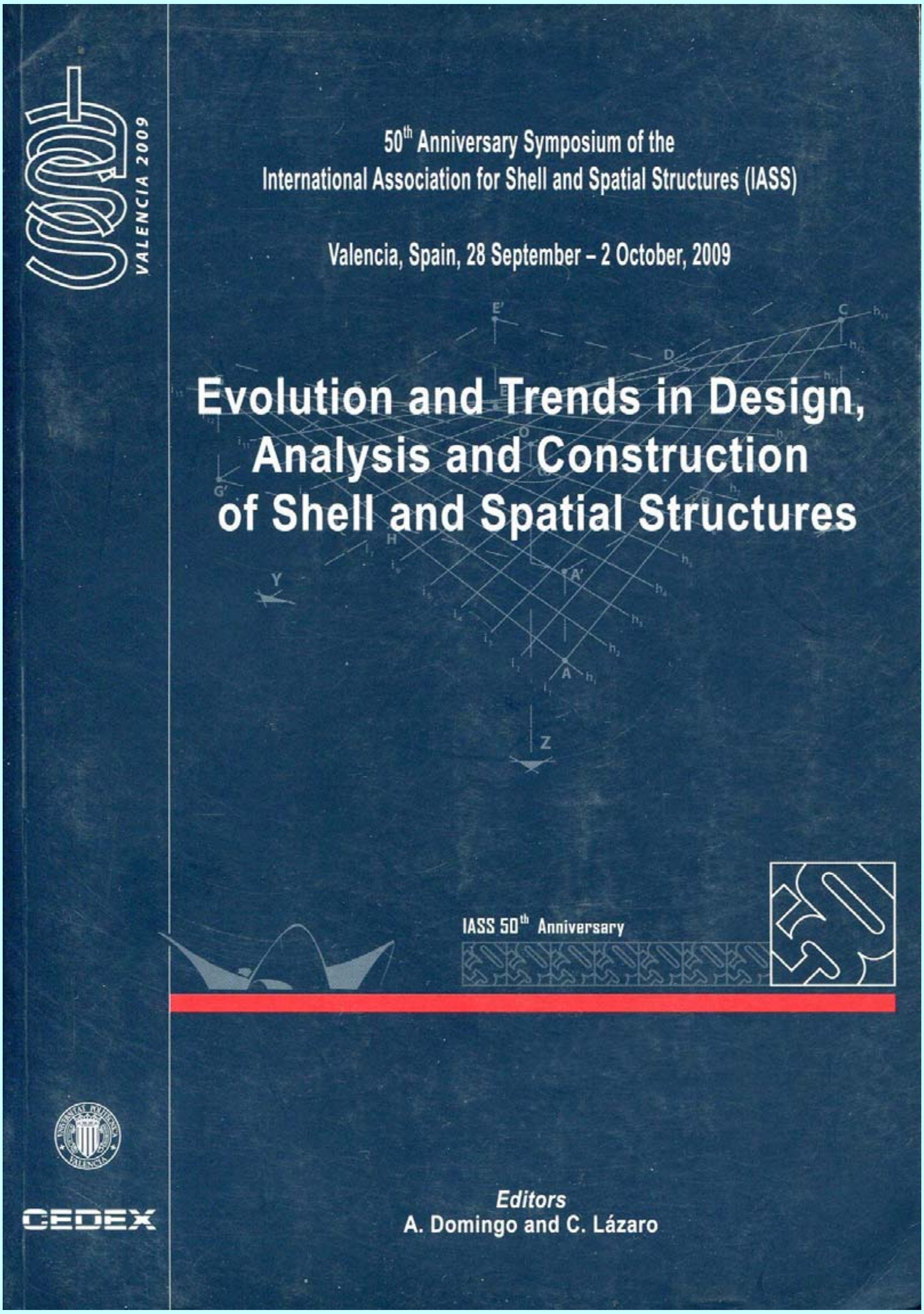
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Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures
IASS 50th Anniversary
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A. Domingo and C. Lázaro

About the freedom of free forms

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Abstract

This paper deals with the arrival of freedom at the world of structures giving birth a new generation of forms: the free forms. Its purpose is to analyze, to discuss and to comment critically this singular fact as well as their implications on the designers' task. It is more a philosophical than a technical paper.

For centuries man has imagined new forms for their structures but he has not been always able to analyze and to build them. Before the arrival of the electronic calculus, the representation and analysis of structural forms could be limited to those ones belonging to the Euclidean geometry. The computers broke those limitations and they gave wide freedom to the designers to conceive a new generation of forms; these new forms were called "free forms".

Nowadays any form imagined can be represented, it can be analyzed and it can be built. Nevertheless not any imagined form can become a structural free form. Perhaps it could be a beautiful sculptural form, but not necessarily a structural one. For being a structural form, the inescapable laws of the mechanics must be satisfied. Moreover a structural free form can become an architectural free form just only when aesthetical, functional, environmental and social requirements, among others, are accomplished.

Freedom has widened the horizons of creativity for the designers' task. Simultaneously new responsibilities have come altogether with this freedom. Today free form designers face permanent challenges; designers must be familiar with the menus of new and multiple tools created by the modern technology and they must be trained to make the right use of them. They must handle those wide menus in order to select the most appropriated options to generate, to model and to analyze the new free forms. At the same time they must select the most appropriated new materials and techniques to build these free forms. Finally, designer must be fully conscious of the high impact of their engineering and architectural works on the people and physical environment without forgetting their commitment to the society.

Keywords: free forms, morphology, morphogenesis, form design, structural analysis, technical requirements, social requirements.

"…*And thus it is possible to build successfully forms so varied…that is only the announcement and proclamation of the* ***revolution*** *that is approaching in the field of the architecture, whose vocabulary of plastic forms is opening and widening with rapidity and imaginative fecundity not known in all the history of the construction"* (Translated from the Spanish original text, Torroja [1]).

The above words were written by EduardoTorroja in 1957; they are an expression of his visionary thought about the future of construction. The following paragraphs are devoted to discuss that **revolution** anticipated by him.

1. Introduction

For centuries man has imagined new forms for their structures but he has not had always the necessary skills and tools to analyze and to build them. The historical evolution of the creation of new structural forms was strongly and permanently linked to his ability to design and to analyze their conceptions.

On the other hand, design and analysis have not had always the same grade of development along history. At the beginning and from very remote times, man did not have more tools than his imagination, his audacity, his mind's eye and common sense to conceive and to build structures. At the same time "trial and error" was the most primitive and valuable tool to verify the safety of his works. By then his competence to conceive a work was superior to his capability to analyze it, that is to say, design had a higher level of development than analysis: man was able to conceive works that he was not able to analyze. Later the accumulated experience gave place to the development of empiricism which became a new tool for the design and construction of structural forms. Until this point, the analysis could offer no more than the "trial and error" method and the help of intuition for verifying the behaviour of structures. Nevertheless famous new structures were built thanks to the ingenuity and boldness of man. Many of those structures have lasted until our days and we admire them like real master pieces.

The capability of the analysis increased greatly in the XVIII century thanks to the development of the sciences and the birth of the Engineering as a professional activity. Mathematics and Physics became strong tools for better understanding and analyzing the behaviour of the structures. Man was able not only to design but also to analyze many structures than he could never do before. However there still were limitations: just only those structural forms belonging to the Euclidian geometry could be analyzed; man could conceive other new forms which he was not able to analyze. More recently we can point out new stages on the developments of structural forms as it will be shown in the following lines.

2. From A.M. Haas to the computer age

*"One selects the correct form (with the architectural draft) then half work is already done". (*Translated
(Translated from original German text, Haas [2])

More than thirty years ago I read the above slogan written by A. M. Haas, IASS past-president and very well known authority in the field of structural shells. I was impressed by his unquestionable truth and I have repeated this slogan for many years to illustrate the emphasis on the importance of the form for designing structural shells. It was just a few months ago when I read again the same text but, then a word caught my eye: ***selects***. In fact, Haas used to *select* and not to *design* as we might say today. By the time when Haas wrote his slogan the designer was restricted to those forms included in the catalogue of the Euclidian Geometry because they and only they were able to be analyzed with the tools available by then. In the 60's a new tool was incorporated in the field of structural analysis: the computer. The arrival of this instrument made a break point in the history of construction as Ben Arroyo [3] pointed out: for the first time the capabilities of the analysis overcame those ones of the design. New roads began to be opened for the designers because the analysis was able to attack new forms not included in the catalogue of the classical Geometry. Designers were able to create a new variety of forms.

3. Morphogenesis

The arrival of the computers pushed the development of a new discipline in the structural field: the structural morphogenesis i.e. the generation of new structural forms. Before the computer age only very few forms not generated by geometry were applied in the construction. For instance the funicular shapes, generated by mechanical principles, were used by A. Gaudí, perhaps the first, or at least, one of the first forerunners in the field of structural morphogenesis.

This advancement in the capability for generating new structural forms brings us to new considerations from the aesthetical and mechanical points of view.

Twenty years ago, for the 40th Anniversary IASS Congress (Madrid 1999), I wrote: "In Architecture as well as in Engineering, the concepts of *shape, space and structure* are strongly linked and connected with three different learning disciplines: ***Geometry***, *Aesthetics and Mechanics*."(Andrés [4]). Now I wish to point out here a great new change:

instead of "geometry" I must say today "morphogenesis". In fact, instead of geometry we must speak today of morphogenesis as a more extensive discipline which encloses the geometry in the field of structures. Beyond geometry, we have today many other ways to generate structural shapes: there are numerical models, physical models, hybrid models, biological models, etc. Some of these models not only generate the structural form, moreover simultaneously guarantees the fulfillment of mechanical laws as it is, for example, the homeostatic model technique (Andrés [5]). Fig. 1 illustrates the famous project by Arch. F. Vivas for the Táchira Club of Caracas. It was one of the first free forms which structural analysis demanded great effort to E. Torroja in 1957, (Tarragó [6]); nowadays a similar project can be designed and analyzed with much less time and effort through the homeostatic model technique, Fig. 2.

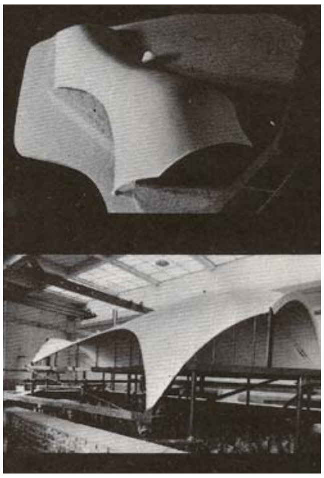

Fig.1. Vivas's and Torroja's Models (1957)

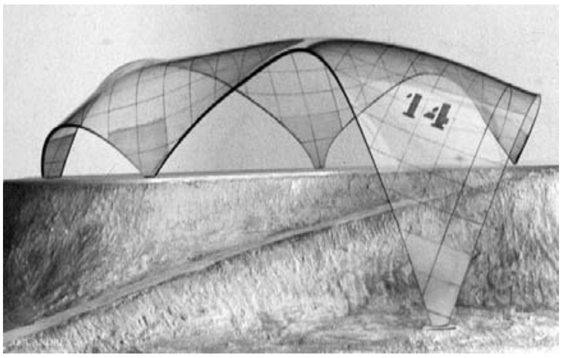

Fig. 2 Andrés's Homeostatic Model (1991)

Morphogenesis allows us to create new shapes and at the same time, shapes define limits in the space in such a way that they create an organization of this space; their visual perception impresses our spirit leading us to elaborate critical judgment about the aesthetic value of that organized space. On the other hand, when a shape is materialized as a piece of a building or construction it becomes a source of strength with great value in Structural Mechanics. All the above concepts and their relationships are synthesized in two triangles: Fig. 3 (according to the old conception, 1999) and Fig. 4 (according to the new conception).

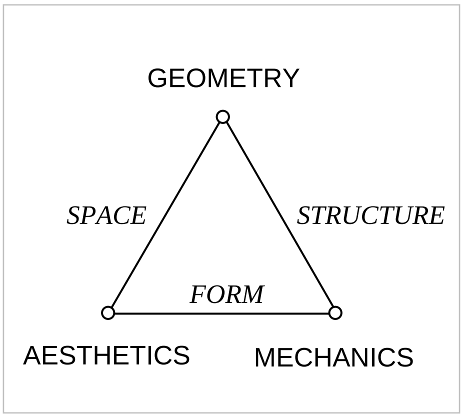

Fig. 3. Old Triangle (1999)

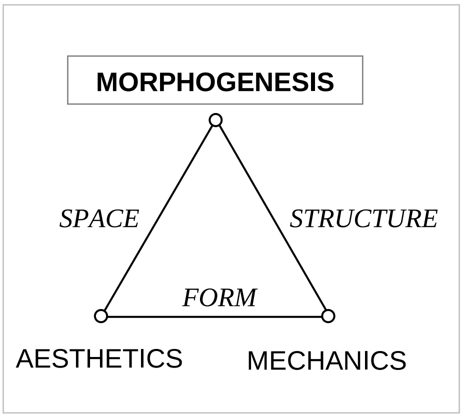

Fig. 4. New Triangle (2009)

4. Free forms

Nowadays, designers are no more constrained to the limits of geometric forms i.e. to select a form from the catalogue of geometry; morphogenesis allows the designers to create an endless variety of new forms, taking advantage of the freedom that they have never had in the history of Construction and giving place to the birth of a new generation of forms: this new generation of forms is called today *free forms*. More than 50 years ago Eduardo Torroja foresaw this advancement as it is pointed out with the words which head this paper.

Sculptural forms are absolutely free as pure expression of their creators. In Architecture as well as in Engineering, structural forms are not absolutely free: their generation is independent of the geometry, but from a technical point of view they must respect the classical Vitruvius’s [7] principles: “utililitas, firmitas et venustas” namely the fulfillment of function, structure and aesthetics. Of course, designers can perform the compatibility and priority of these principles according to their criteria which will remain reflected in their creation.

Free forms have called the attention of a great majority of designers; today they are widely known and so we can see them very often in technical publications and in the real world of construction. In the evolution of Architecture, free forms are a new landmark due mainly to the morphogenesis, as the introduction of the computer set a landmark in the evolution of Structural Engineering half a century ago.

5. Free forms in the present society.

The morphogenesis has given new freedom to designers, but as every new freedom it claims for new responsibilities facing society. Technical responsibilities must be satisfied without forgetting the social responsibilities: ethical, economic and environmental requirements which must be at all times considered and respected by current designers

Computers and morphology have given extraordinary potentiality to designer's task: from a technical point of view, today it is possible to represent, to analyze, and to build any kind of structural form, but from a social point of view not every form must be transformed in a real building. Sometimes very complicated designs look as a demonstration of the designer's skills to cope with sophisticated soft wares as well as an exhibition of their personal vanity, more than a sincere expression led to satisfy technical and social requirements.

This brings us to point out that an obsessive and exorbitant use of morphogenesis together with computer techniques could be negative for development of designer's imagination. At the same time, this could contribute to show an impression of indifference and insensitivity of those designers facing the society.

Finally we should not forget the words of F. Otto [8]: *"Structures cannot be designed arbitrary"*. Designers must always be very careful and reasonable regarding the use of materials and human work. Common sense should be always present in every design: from every point of view it is not suitable to waste natural resources and human efforts.

6. Concluding remark

- Computer and morphogenesis techniques together with new building technologies and materials have given place to the birth and development of free form structures.
- Free forms are today an unquestionable landmark in the historical evolution of Architecture and Engineering.
- Let's architects and engineers be respectful and conscious about society's requirements, so as not be stigmatized by the hard words of Theodore Roszak: *"technologists look at the world with dead man's eyes"* (Florman [9])

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From Spatial Structures to Space Structures

Innovation in homeostatic model technique to generate free forms

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"One does not actually create the form;
one lets it become, as it has to according to its own law."
Heinz Isler [1]

Summary

This paper deals with physical models built through HMT (Homeostatic Model Technique). It is used to generate free forms of dominant compression by means of physical models. Previous papers of the author explain basic ideas, procedure of the technique itself as well as verifications and its advantages. The purpose of this paper is to introduce a very simple and useful innovation: it allows a great increase in the number of new forms by modifying the curvatures of the shell models through the control of the horizontal components of the external reactive forces.

Keywords: morphology; morphogenesis; shell; physical model; thermo-plastic.

1. Introduction

A great variety of new free forms have been created during the last decade due to advancements in Morphogenesis. New techniques have been developed following both theoretical and experimental methods.This paper deals with physical models built through HMT (Homeostatic Model Technique). It is used to generate free forms of dominant compression. Previous papers of the author [2, 3] explain basic ideas, procedure of the technique itself as well as verifications and its advantages. The purpose of this last innovation is to greatly increase the number of new forms by modifying the curvatures of the shell models. Modifications are introduced through simple handling of external reactive forces.

In order to emphasize differences and improvements, following we will refer later separately to the former homeostatic models built before this innovation and next, to the new homeostatic models.

2. The former homeostatic model

2.1 The fundamentals

Although previous IASS papers explain the fundamentals of the HMT, a brief explanation of its basic principles is given here:

The generation of the model is obtained by adding up two different actions: a) load action, and b) heat action.

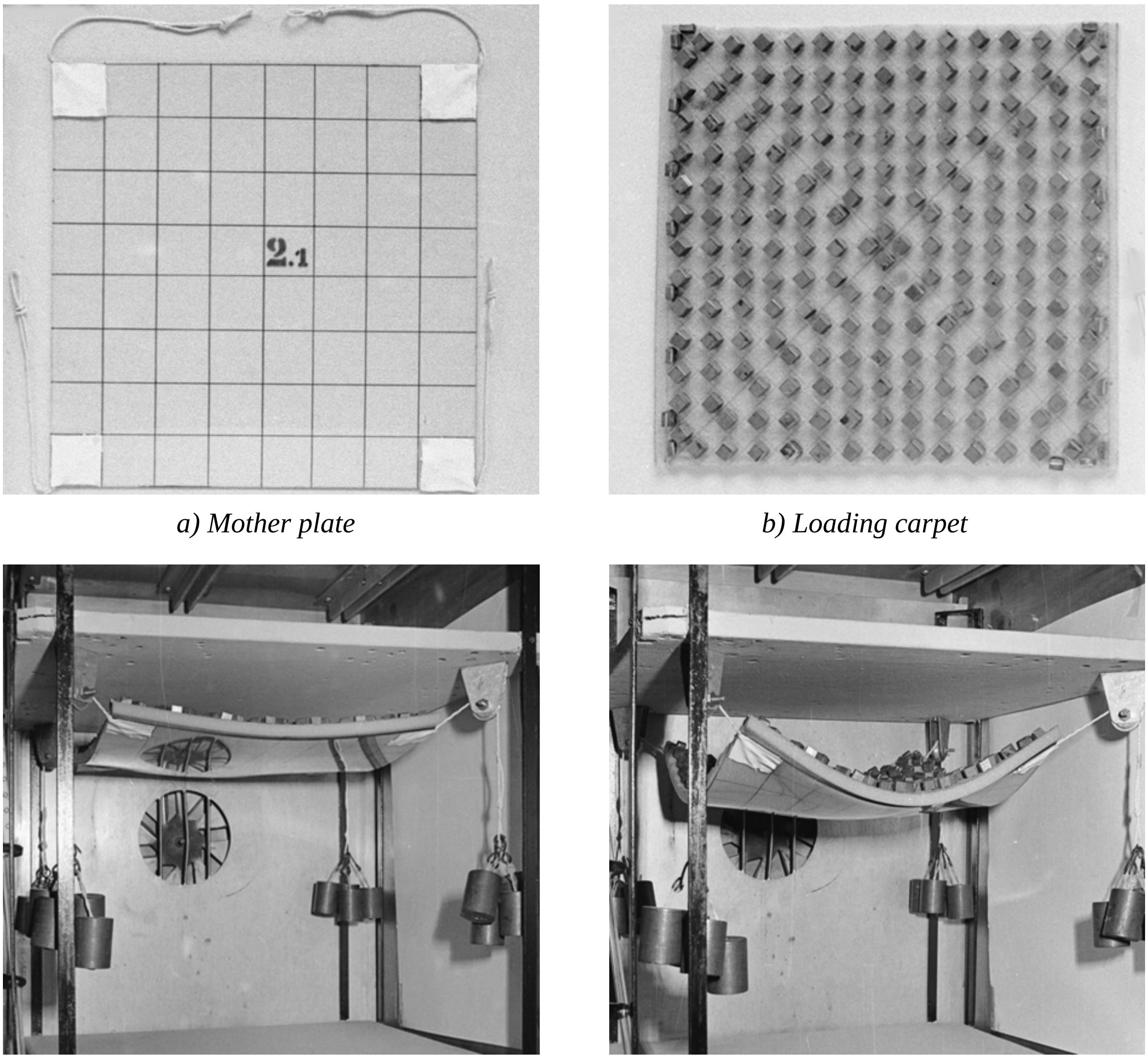
The introduction of the heat action is linked to the phenomenon known in Physiology as homeostasis. According to this phenomenon, all living creatures tend to restore the balance of its vital functions when they are attacked by an external agent. In the same way, and having in mind the parallelism between living creatures and structures (largely studied by A.Gaudí, F.Cardellach, E.Torroja), when a structure is attacked by an external agent (loads, for example) it develops automatically intelligent actions to avoid the collapse.

In the case of the homeostatic model the external agents are loads plus heat. So when a thermoplastic plate is heated in an oven its mechanical properties are degraded. The plate can no more resist the bending as a plate, then, it becomes a membrane taking the loads by traction.

Once the model has cooled the material recovers its original stiffness; by inverting its position we have a dominant compression form.

2.2 Construction of the former models

A short explanation about the construction of the former homeostatic models follows here:



a) Mother plate

b) Loading carpet

c) The model comes into the oven as plate

d) The model leaves the oven as membrane

Fig. 1: Former model

The mother plate (thus named because it will generate the model) is made of a thermoplastic flat plate 2mm thick. Its perimeter shape and suspension points are selected by the designer (Fig. 1). This plate is suspended from its suspension points by means of threads adhered to them. These threads, after being threaded through pulleys, are tied by their ends to weights in order to balance a uniformly distributed load placed on the plate by means of a loading carpet. This load is assumed as the predominant load for the design of the structure. The assembly cage--plate, loads and weights--is put in an oven and heated to approximately 120ºC. The homeostasis then occurs: the plate becomes a shell, passing from a dominant flexure form to a dominant traction form. Once the model is cooled, the thermoplastic recovers its mechanical properties; the shape thus obtained is then "frozen". Now it is only necessary to invert the model to have a dominant compression form.

Then it is possible to measure its X, Y and Z coordinates of a network of points on the surface of the model. This operation is rapidly and safety made by means of a digitizer arm (a 3D scanner). The total files of the coordinates allow us to transform the physical model into a numerical model that can be fully analyzed.

3. The innovation

3.1 Basic idea

The homeostatic HMT was conceived by the author in 1988 [4]. Since then all the homeostatic models built up to now have only one thread per each suspension point (supporting point once the model is inverted). Instead of that we put now a second thread per each suspension point, so we have two weights per suspension point to balance the weight of the mother plate plus the loading carpet.

The balance between loads and forces on the suspension points requires two conditions:

a) Sum of all vertical components of suspension forces must equal the loads (only gravity loads are applied), and

b) Sum of all horizontal components of hanging forces must be equal to zero.

The last condition accepts multiple combinations for each couple of hanging forces. So we have for each combination a different value and direction of the hanging forces. When a change is introduced in the weight of the balancing weights, automatically the directions of hanging forces change to keep the equilibrium. Consequently the curvatures of the surface change and a new form is generated when the assembly cage (plate, loading carpet and balancing weights) is put into the oven and heated.

3.2 Main advantages of this innovation

Among the main advantages introduced by this innovation we can point out:

a) Before putting the model in the oven the designer has whole freedom to choose the form of perimeter of the plate, the position and number of the supporting points, the edge conditions and loads.

b) After that, once the door of the oven is closed the freedom ends. The true designer of the new structural form will be nature through its unavoidable and changeless laws.

c) When the new form obtained is not the most adequate for the requirements of the designer, he can introduce all the desired modifications by applying the innovation above explained, i.e. changing the relationship:

$$R= W_1/W_2 \qquad (1)$$

Where:

W_1: weight of the smallest reactive force acting in one suspension point and

$W_{2:}$ weight of the biggest reactive force acting on the same point.

Fig. 2: Model 220 in the oven with
R = 1,00

Fig. 3: Model 220 in the oven with
R = 0,38

To introduce this modification is a very simple and quick task because you only must change the balancing weights until you achieve the desired value of R. A model with two different R values is shown in Fig. 2 and 3.

Moreover, you don’t need to change the mother plate to do this modification. So the operation becomes economical because the same mother plate can be used until the desired form is achieved. The mother plate works as a 3D draft.

4. The new homeostatic models

4.1 Some new models recently built

New models recently built through the above mentioned innovation are shown in the following photographs; some were taken during the construction of the models and some others, once the models were finished.

4.2 Model 219

These models of a roof were designed to cover a large room; both were made with the same mother plate and loading carpet, but with different value for the relationship R. (Fig. 4, 5, 6 and 7).

The form differences of both models can be clearly appreciated in Fig. 6 and 7. It is pointed out that both models were built with the same sole mother plate shown in Fig.4.

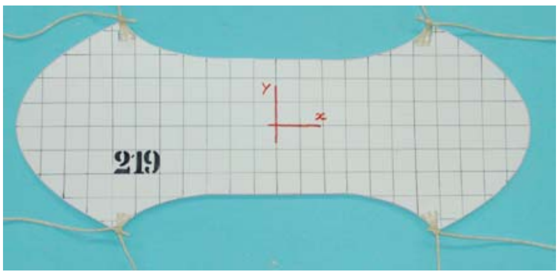


Fig. 4: Mother plate

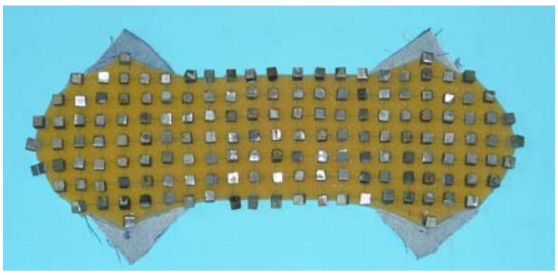


Fig. 5: Loading carpet

Fig. 6: Model 219 built with R = 0,00

Fig. 7: Model 219 built with R = 0,25

4.3 Models 220.1 and 220.2

These models were conceived as two roofs to cover large rooms for two different uses having consequently two different forms. Their construction is shown in previous Fig. 2 and 3.

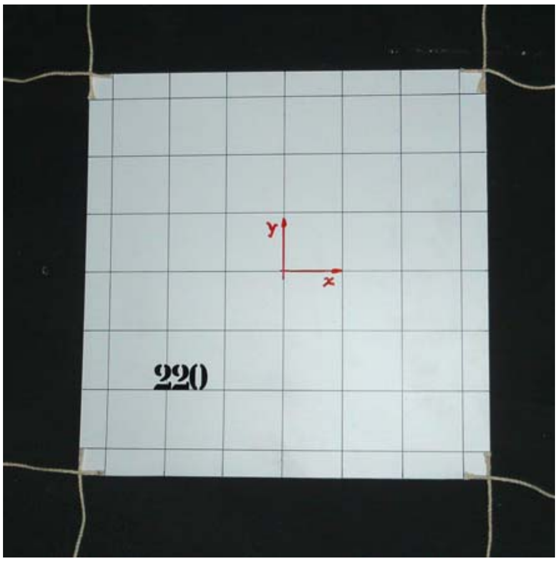


Fig. 8: Mother plate for models 220.1 and 220.2

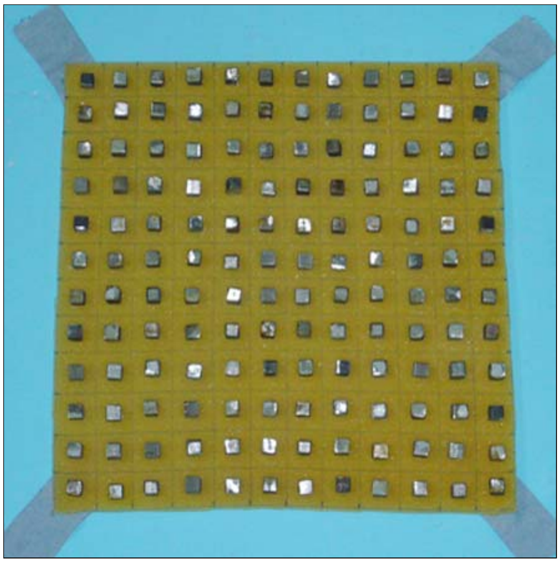


Fig. 9: Loading carpet for models 220.1 and 220.2

It is pointed out the difference between the former model with only one thread per corner (Fig. 1a) and the new model with two threads per corner (Fig. 8).

The form differences of both models 220.1 and 220.2 can be clearly appreciated in Fig. 10 and 11.

Again here it is pointed out that both models were built with the same sole mother plate shown in Fig. 8. This means that material and time are saved because it is not necessary to construct an other model; the same model is modified by changing the balancing weight to get the change from R = 1,00 to R = 0,04. (The smallest weight belongs to the direction of the X axe). Both models have four supporting points and free edges.

Fig. 10: Model 220.1 with relationship R = 1,00

Fig. 11: Model 220.2 with relationship R = 0,04

4.4 Model for a landmark entrance

Fig.12: Landmark model.

This model has been conceived as a landmark to be located at the entrance of an educational institution.

It is composed by two elements: the tower and the shell.

The tower has been thought to be built in reinforced concrete, while the shell will be built in ferro cement on the ground and after that it will be elevated to its finishing position.

The shell has been designed by HMT.

It has free edges and three supporting points.

4.5 Replica model of one of the master pieces of Heinz Isler

Fig. 13: Replica HMT model of the Deitingen Service Station (Switzerland, H. Isler)

This new HMT model is a replica of the Deitingen Service Station (Switzerland, 1968). It has been conceived with a double purpose. Firstly, to pay a modest homage to the memory of Heinz Isler, designer of that creation and great master in form finding structures; and secondly to show the versatility of the HMT through the innovation here introduced.

5. Conclusions

The new models built through the HMT with the innovation here detailed prove the potentiality and freedom given to the designer. He has a new tool which opens the doors to a wider creativity.

6. Acknowledgement

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