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## Fifty years of progress for shell and spatial Structures

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# THE FIFTH DECADE

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## 1. INTRODUCTION

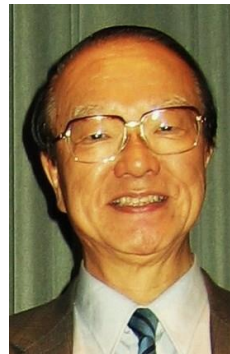
This fifth decade is the first of this new century, and simultaneously of a new Millennium according to the calendar in practice for most of us. The turn of Millennium is always a very specific time for people: it could be understood as a key point, a point of irreversibility between past and future, but also it is mainly understood as a “new era” giving the opportunity to create new situations and for the members of IASS new Shell and Spatial Structures. It will be the appropriate time for developments that did not occur before. Men are always in between the past, their roots, and the future, their projects. These aspects are reflected in the titles of our symposia and specifically in the titles of the last symposium of the second Millennium [1], and the first symposium of the present one [2]. Looking to this fifth decade is difficult since this is precisely the present time, this is not exactly a work of history, it is not yet a work of project, but all the published documents that are available are very useful for achieving this work, and mainly among them, the Journal of our International Association for Shell and Spatial Structures.

## 2. THE ACTORS

As for any human association, nothing can be done without men and women who are the main actors of the different components of the organization: working bureau, executive council, advisory board.

### 2.1 Two presidents for a decade and “a permanent secretary”

During the annual symposium held in Istanbul in May 2000, the executive elected Prof. Mamoru Kawaguchi (Japan) as new IASS President.



*Figure 1. Professor Mamoru Kawaguchi* “Prof. Kawaguchi was born in Fukui, Japan, in 1932. With his design office, **KAWAGUCHI & ENGINEERS**, he has been involved in structural design of a number of important buildings with a variety of structural systems. Among his realized structures are the Grand Roof for Expo’70 in Osaka with a double-layer space frame, the Fuji Group Pavilion for the Expo’70 with an air-inflated membrane Structure, and the West Japan Exhibition Center with a cable-stayed roof system. He also developed a structural system that he named the “Pantadome System”, applicable to domical of any possible shapes and by which they can be constructed with high safety, speed, and economy[3]. He received the Torroja Medal in 2001, and was also recognized as an Honorary Member of our association (2007), as is the previous President Prof. Medwadowski (2001).



*Figure 2. Professor John Abel* Professor Mamoru Kawaguchi completed two terms in the presidency (2000-06). The second president of the decade is Professor John Abel, elected in 2006. He graduated from Cornell University in 1963, moved to Stanford University for his M.S. just before his Ph. D. at Berkeley, California.

During his research career, he has worked on such topics as concrete shells (especially cooling towers), membrane roofs, domes, steel framed

structures, earthquake engineering, computer-aided design, computational mechanics, and interactive computer graphics for engineering applications and education.

He is the author or co-author of over 200 papers and reports, dealing mainly with computer-related topics in structural engineering. He is the co-author (with C. S. Desai) of one of the earliest published textbooks on the finite element method, *Introduction to the Finite Element Method* (1972), which was later translated into Japanese and Chinese.



**Figure 3.** Rafael Astudillo

Beside these two presidents, somebody is always working hardly with a very singular sense of humility. He is the “shadow man”. Without him, since many years nothing could have been done, Rafael Astudillo Pastor, the Director of the Laboratorio Central de Estructuras, one the vice presidents of IASS, is simultaneously the memory and the kingpin of the association.

## 2.2 Distinguished people

This is always a difficult task to identify people who were in front of our history by avoiding to forget one of them. During the fifth decade several people were honored for their works: Jörg Schlaich, David P. Billington, Tien T. Lan, Mircea Mihailescu and Porfirio Ballesteros



**Figure 4.** Jörg Schlaich and David P. Billington. Montpellier 2004

*“Professor Jörg Schlaich (the first Torroja Medal Winner of the decade) contributed a lot to the field of lightweight spatial structures. Some of his works go beyond merely national design of structures, trying to make structural engineering contribute to social problems such as global energy issues. He also led the IASS annual symposium in Stuttgart devoted to “Conceptual Design” (1996) as quoted by M. Kawaguchi [4].*

Professor Billington, awarded in 2004 as Honorary Member “started his professional career as a researcher of shell structures, and carried out excellent works in that field. Later he devoted himself to exploration of the works of “structural artists” such as Robert Maillart, Christian Menn and Heinz Isler. He has been advocating the importance of structural art, and has written several excellent books on this theme. His book, “The Tower and the Bridge” [5] is one of the most remarkable writings in the field of structural design.” [6]

Professor Tien T. Lan and Professor M. Mihailescu have been named Honorary Members. Professor Tien T. Lan achieved a wonderful work to promote shell and spatial structures in China, contributing to this objective by his writings, published since many years in International Journals, helping his colleagues to organize a wonderful symposium in China in 2006 [7].

Professor Mircea Mihailescu was a concrete shell designer who achieved many works in his country, Romania, during a very difficult period politically speaking. His designs were governed by analytic solutions. Unfortunately M. Mihailescu passed away suddenly a year after the IASS Symposium that he organized in Bucharest, in 2006.



**Figure 5.** Porfirio Ballesteros in Acapulco

Professor Ballesteros has been a member of IASS since 1962 and has served continuously on the IASS Editorial Committee since its inception. His academic career in structural engineering began in 1959 and culminated with his retirement from UNAM. Also in 1959, he founded his own structural and design office, which has completed over 7,000 projects, including many concrete shell

roofs, one outstanding example being the Iglesia de Neustra Señora de Fátima in Monterey.

### 2.3 Memory

The third annual Issue of the *Journal* of the IASS usually contains a “Letter from the president” where the memory of famous members is evoked.

*“In 2004, we suffered grievous losses with the passing away of our precious members Lajos Kollàr and Georgy Khaidukov. Professor Kollàr was not only an excellent scientist but also a distinguished engineer in Hungary. He wrote many fine books on such important subjects as stability of shells and tension structures, and designed several shell and spatial structures. ... Professor Khaidukov was also a renowned scientist-engineer. Beside international acknowledged excellent works in the field of structural engineering, he established the Laboratory of Thin-Walled and Spatial Structures in Moscow, and greatly contributed to the development of shell and spatial structures in Russia..” [4].*

In 2005 Mamoru Kawaguchi wrote *“...I have to report with great sorrow that we suffered a woeful loss in October with the passing away of Professor Z.S. Makowski. As all the members of the IASS know, Professor Makowski was a leading International authority on space structures for many years. He established the Space Structure Research Centre at the University of Surrey, which played a role of Mecca for study of spatial structures, inviting students and researchers on related subjects from all over the world. In 1966 Professor Z.S. Makowski organized with his collaborators the first International Conference on Space Structures, which became the start of a series of worldwide conferences to be held at an interval of nine years. He also founded the International Journal of Space Structures, in 1985 together with his collaborator, Professor H. Nooshin.”[8]*



*Professor Wolfgang Zerna passed away in November 2005 : he was a pioneer in the areas of structural mechanics and thin-shell concrete structures, especially cooling*

*towers.*

**Figure 6** Professor Z.S. Makowski and Nooshin. Guildford 2002

*In October 2006, Professor Mircea Mihailescu died unexpectedly as it was written in the preceding paragraph [9].*

*The year after, “one of our Honorary Members Professor Alexander C. Scordelis died in August. A Professor at the University of California at Berkeley, Alex was not only a long-time member of IASS and an expert on concrete shells and long span bridges, but also the recipient of the Association’s highest honor, the Eduardo Torroja Medal” [10].*

Ture Wester, a very active member of IASS as chairman and founder of the working group “Structural Morphology”, as member of Executive Council, Advisory Board and several Committees died at the end of 2008. As searcher and teacher, Ture Wester developed always wonderful studies based on a clever observation of the natural systems [12]. Heinz Isler who supported him in Copenhagen for promoting the working group on Structural Morphology passed away in 2009.

## 3. SCIENTIFIC ACTIVITIES

### 3.1. Introduction

IASS has always been an association at the meeting point of engineers, architects, mathematicians and even artists. Its scientific activities are clearly displayed every year during the annual symposium, but also during colloquia held by its working groups. During the fifth decade, IASS sponsored and/or co organized also many symposia and colloquia. It is not worthy to enumerate all these scientific events; their list can be seen on our website. Only specific features will be developed in the following paragraph.

### 3.2. IASS Symposia and sponsored events

The international character of the association appears clearly with the successive places where the annual symposium is organized : Turkey (Istanbul), Japan (Nagoya), Warsaw (Poland), Taipei (Taiwan), Montpellier (France), Bucharest (Romania), Beijing (China), Venice (Italy), Acapulco (Mexico) and this year Valencia (Spain) – continuing the tradition of returning to Spain every 10 years.

It is a matter of fact that IASS is growing in the Asia Pacific part of the world. Two events



characterize this geographical expansion:

- In May 2001 Korean colleagues established KASS (Korean Association for Shell and Spatial Structures) which is chaired by Prof. T.J. Kwun. The inauguration ceremony took place on May 26 (Prof. M. Kawaguchi and T.T. Lan were present). The year 2001 has been a special year for Korea in terms of spatial structures, since ten stadiums were newly built there for the World Cup Football Games of 2002, and since this year an increasing number of Korean engineers and architects became interested in the activities of the IASS.
- Two times during this decade the annual symposium was a joined IASS-APCS (Asia Pacific Conference on Shell and Spatial Structures) namely in Taipei (2003) and Beijing (2006). APCS is now very well established in this geographic area. This year 2009, Professor H. Ohmori is organizing the sixth APCS in Nagoya.

It is also important to note that in June 2002 our Symposium has been organized by the Polish Chapter of the IASS, which was led by Prof. Jan B. Obrebski. We all know the necessary energy for this kind of organization. Three years thereafter Prof. M. Mihailescu organized also an annual symposium demonstrating the interest of the East European countries despite difficult economic conditions, keeping alive the worldwide collaboration of people interested in shell and spatial structures.

One last main feature that I wish to quote is the close collaboration between IASS and IACM (International Association for Computational Mechanics) supported by the Working Group 13 "Numerical Methods". They have organized three meetings, the first in Chania (Greece, 2000), the second in Salzburg (Austria, 2005) and lastly in Ithaca (USA, 2008). These meetings are very useful for explaining the mechanical behavior of shell and spatial structures, for developing new numerical simulations taking advantage of recent theoretical developments like neuronal methods, and genetic algorithms.

Another link is threaded by sponsoring conferences on topics that are of interest for IASS members:

- Structural Morphology (Adaptables' 06, Bridges'08 are some examples).
- Metal structures ("The Metalwork in Civil Engineering : State of the Art and Perspectives" Kiev 2006 and IX Ukrainian Scientific and Technical Conference – 2008)
- Dynamic aspects ("10<sup>th</sup> World Conference on Seismic Isolation, Energy Dissipation and Active Vibrations Control of Structures" Istanbul 2007). Information about the proceedings can be found at the web page of TASI [www.did.org.tr](http://www.did.org.tr) .[13]
- Structural Engineers World Congress 2007. SEWC organized by R. Sundaram, another tireless member of IASS[14]. Co sponsored by IASS whose members were very numerous among the delegates.
- Tension Structures (2<sup>nd</sup> Latin America Symposium on Tension Structures – Caracas 2005)[15].

### 3.3 Working Groups

A major part of the association's life relies on working groups activities. Every year the chair of Technical Activities Committee publishes a report in the third Issue of the Journal of IASS [16]. 12 working groups among 19 are still active and their dynamism is depending upon many factors. Some of them are geographically restrained in one or another country, or a group of countries in same part of the world: practical and economical reasons explain this characteristic. But it is also understandable that local specificities are a motivation for some specific studies: dynamic aspects are especially under study in countries where earthquakes are more frequent. Diversity is the key word of the activities of working groups. This diversity is also dependent upon economic factors, dynamism of the chairperson, improvement of technology and/or theoretical studies...

All working groups are publishing texts: state of art, recommendations, colloquia proceedings, special issues of scientific journals. This external communication is since two years supported by the website of the association, which plays now a major role for IASS members and non members.

Three working groups, Tanks and Silos, Cooling Towers, and Concrete Shell Roofs are identified by a common material: concrete. The first one is now in a process of transition of chairmanship, and reforming. Four colloquia were organized by Professor Popovsky, in a restricted geographical area, and unfortunately we do not have printed texts of these meetings. Professor Rotter (UK) is actually in charge of this working group. Taking the advantage of several national meetings held in Germany, the working group on cooling towers published a New VGB Technical Guideline in German (2005) and then in English (2006). In close cooperation with U. Wittek, chairman of the group, I. Mungan organized the “Fifth International Symposium on Natural Draught Cooling Towers” in Istanbul in 2004 [17]. Two main actors of the third working group concerned with concrete died during this decade : Professors Kollar (chairman until 2003) and Professor M. Mihailescu. Despite these sad events the members worked on a state of art report under the actual guidance of Professors Abel and Tarnai. Three chapters of this report have been published in the Journal of the Association ; they are dealing with “Shape Finding” [18], “Design of Reinforcement”[19],and Buckling of Concrete Shells” [20]. Two other chapters (“Computer Methods of Analysis” and “Construction Methods and Quality Control”) are under work.

“Masts and Towers” (WG4) organizes regularly biannual scientific meetings. Four meetings were held in Oslo (Norway, 2001), Milan (Italy, 2003), Moscow (Russia, 2005) and Montreal (Canada, 2007) during this decade, and the last one will be held in Helsinki in September 2009. “Recommendations for safe Systems for access on Masts and Towers”, and proceedings of Milan meeting are available (on request directly at the secretariat of IASS <iass@cedex.es> for the recommendations, and a copy of the CD of Milan’s papers can be obtained at the secretary of the WG [mon@ramboll.dk](mailto:mon@ramboll.dk)). Prof. Brian W. Smith has published the book “Communication Structures” [21] with WG4 as the backing group. Mauro Eugenio Giuliani wrote the associated book review in a recent Issue of the Journal [22].

After its contribution to the double special Issue on “Recent Spatial Structures in Japan” [23] at the beginning of the decade, the working group on “Tension and Membrane Structures” tries to find a

new vitality extending its composition, which is actually mainly restricted to Japan, but weaving links with other countries and mainly in Europe, taking advantage of the activities of groups like Tensinet, chaired by M. Mollaert. Activities of “Metal Spatial Structures” are mainly focused on buckling problems, and more recently on dynamic problems. In 2005 a new sub Group on Dynamic Aspects of Metal Structures has been established by the executive council; it is chaired by Prof. S. Kato.

Always inspired by new action, tireless actor of IASS, Prof. I. Mungan has organized in June 2009 an International Symposium in Istanbul “Timber structures from Antiquity to the present” in cooperation with Prof. J. Chilton, chairman of WG 12, “Timber Spatial Structures”.



**Figure 7** Prof. I. Mungan – Bangalore 2007

Prof. A. Samartin and H. Ohmori are chairing the working group on “Computational Methods in Shell and Spatial Structures”, which is obviously a key group since computation was and remains a major step in shell and spatial structures design. Two main kinds of events have to be put forward. The first one has soon been evoked in a preceding paragraph: the coorganization of IASS-IACM conference three times in the decade, opening the scope of people dealing with computational methods applied to shell and spatial structures. The second one is the creation of a subgroup on Computational Morphogenesis on basis of a proposal by H. Ohmori in 2005, who organized the year after an international conference in Nagoya. IWCS06 [24]. This subgroup addresses clearly one of the new problems related with “Free Form Design” which are one of the main features of this decade.

The subgroup Computational Morphogenesis participated to the Sixth International Seminar of Working Group 15 “Structural Morphology”. This seminar was devoted to “Morphogenesis”. Ture Wester acted as chairman of the Working Group Structural Morphology until 2004, and René Motro did the same job for four years before transmitting “the baton” to younger people largely involved in this field. During the fifth decade this working group organized three international seminars in Delft (Netherlands, 2000), Montpellier (France,

2004) and Acapulco (Mexico, 2008), and published five newsletters with the precious help of J. Coenders. A new subgroup was established in 2005 to take into account new trends linked with “Free Form Design”. In 2006 a workshop [25] was organized in Delft by the actual chairman of the group, A. Borgart, and some papers presented there, were included in a special electronic Issue of the Journal [26]. In 2007 the working group organized another workshop in France devoted to free form surfaces.

Taking advantage of the immense work realized by the working group, an “Anthology of Structural Morphology” gathering the most significant papers published by the members of the working group has been edited, and is under press [27].



**Figure 8** Workshop on free form surfaces. Isle d’Abeau, France, 2007

Görün Arun, who is in charge of the Working Group 17 “Historical Structures” organized a symposium on Historical Heritage which provides an interesting point of view concerning the link between shell and spatial structures and historical structures [28].

Taking account of the new era of our world, that requires a better understanding of environmental constraints, the WG 18 ECS (Environmentally Compatible Spatial Structures) held three seminars in Prague during the decade. The results of these geographically restricted meetings have now to be largely disseminated among all the members of IASS, by means of the website. This is one of the actual tasks of this group under the guidance of P. Vegh.

The most recent Working Group “Temporary Spatial Structures” chaired by Prof. Murota is in a phases of initial actions, and its program takes account of the increasing number of temporary

structures whose safety has to be ensured.

In its last meeting in Acapulco (2008), the Executive Council strengthened the activity rules of the working groups in order to improve their efficiency and to foster exploration of new ideas and directions. Besides the annual report, they will organize dedicated sessions during the annual symposium of the Association.

### 3.4 Prizes and awards

Since 1991, two Tsuboi Awards are annually granted: (A) For the most meritorious paper published in the Journal of the IASS in the preceding calendar year. (B) For the most outstanding paper presented and published in the Proceedings of the previous year’s annual IASS Symposium.

The list of awardees is given on our website: <http://www.iass-structures.org/>. It is interesting to note that some trends can be seen by reading the titles that are mentioned for these prizes. Authors are mainly interested in:

- dynamic problems related to high rise and long span structures,
- new materials like wood foam sandwich shells, hybrid systems (steel and wood), composites and even ice,
- emerging concepts: tensegrity systems, “blob” architecture, deployable constructions,
- form-finding aspects: computational morphogenesis, traditional geometries and folding possibilities.

The awardees are mainly from Japan and Europe.



**Figure 9.** Prof. Yasuhiko Hangai

Besides these Tsuboi Awards, the classical Torroja Medal, and Honorary Membership, a new prize has been established, the **Hangai Prize**.

The bases of allocation of this prize were discussed in Warsaw in 2002. This is a novel prize for youths (under

thirty). The prize, announced at the Symposium 2001 in Nagoya, is based on the fund donated by Mrs. Naoko Hangai, the widow of the late Prof. Yasuhiko Hangai, who had been a very active member of the Executive Council.

IASS Executive Council decided to establish the prize for young people in conformity with the attitude of late Prof. Hangai, who was always encouraging young researchers warmly.

The prize is given to the winners of the international contest of research papers, resumes of the design/construction projects or resumes of the innovative ideas that are related to the field of shell and spatial structures.

The IASS Hangai Prize committee selects the most innovative papers among the submitted contest papers/resumes and gives the prize to the authors at the next annual symposium. This is an “open door” for youths, who receive the Medal, a Certificate, one year free IASS membership, a special opportunity for presentation at the symposium and some other benefits which may be offered by the organizer of the annual symposium. The first Hangai Prize was attributed in Taipei. The committee is actually chaired by Prof. Takayama from Japan. Homepage of the IASS Hangai Prize is available at the following URL: <http://hangai-prize.iis.u-tokyo.ac.jp/>

Every year a specific “Hangai session” is organized during the Annual IASS Symposium and the attendance is growing from year to year.

#### 4. IASS INFLUENCE

Besides the organization of conferences of any kind, the influence of IASS is conditioned by three main supports: proceedings, the *Journal of the IASS* and more recently the IASS website.

##### 4.1 Proceedings

At least for every annual symposium, the organizers provide the proceedings, and almost all the symposia of the decade have produce a CD of full length or extended abstracts of the papers. It is possible to get the list of all proceedings for symposia, colloquia, seminars and conference at the secretariat of the Association, and then to ask for samples by writing to the related editors.

##### 4.2 The *Journal of the IASS*

Sergio Pellegrino is the new Editor-in-Chief since May 1<sup>st</sup>, 2008. Before him and for many years John Abel occupied this situation. Marta Sánchez de Juan is the Associate Editor. The number of Members of the Editorial Committee is 45.

Several actions contribute to the improvement of the Journal

- On-line Publication. Issues since 2005 have been uploaded in the IASS website (from n. 147 April 2005 to n. 158 August 2008).
- Indexing. Secretariat has initiated the contact with ISI Web of Science for possible indexing.
- On-line Reviewing of Papers. The new IASS website already includes a capability for an on-line system of managing the reviewing and revision processes (starting early 2008).
- Improvements to Journal Review module have been proposed to make the system more suitable to our needs and more robust in tracking and archiving manuscripts and reviews.
- Serving Subscribers by On-Line Publication. Starting in 2009, the website includes facilities for Subscribers to subscribe on line to the print and/or electronic versions of the Journal of the IASS.

##### 4.3 Website of IASS

Thanks to Executive Council’s decisions since several years, and to the effective action of our present President, Prof. John Abel, the Association has an up-to-date tool with its website: <http://www.iass-structures.org/>

It is not the place, in this book, to give an extended list of the website’s possibilities that are increasing from day to day. Every one may have access to this website, and IASS members have the possibility to get more information concerning all the past, present and future activities of the Association.



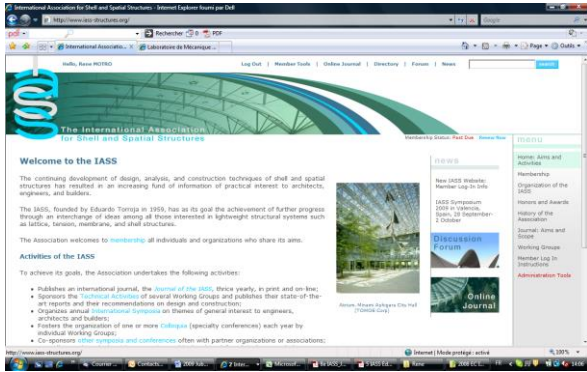


Figure 10 Homepage of IASS website

## 5. SHELL AND SPATIAL STRUCTURES: NEW TRENDS

### 5.1 Introduction

In 1997, a specific IASS colloquium was organized in Madrid with the title “Current and Emerging Technologies of Shell and Spatial Structures”. The goal of the colloquium was to bring together experts to assess the state of the art and the emerging technologies including aspects of design related to lightweight structures [29]. In the preface we could read : “One or more representatives of each working Group presented a lecture at the colloquium...In addition a few contributions by distinguished engineers on other topics related to lightweight topics structures were covered at the Colloquium ...:

- Bridges
- Tensegrity Systems
- Deployable Structures
- Conceptual Design

### 5.2 Main trends and evolution

It is difficult to establish quantitative trends, but it is interesting to note that in this fifth decade, some main evolutions can be underlined. Concrete shells are always a field of study and realizations. Theoretical and numerical developments are characterized by an increase of dynamic and nonlinear studies. Designers and searchers go beyond the classic static design with predefined shapes: infinitesimal mechanics and finite mechanics are better known and Deployable Structures begin to appear in studies and

realizations.



Figure 11 Tensegrity Tower. Rostock, 2003. Schlaich-Bergemann

After searching simply compressed systems (mainly concrete shells), and purely tensioned ones (mainly cable nets and membranes), designers develop new systems associating tension and compression in the same system. Prestress is now currently used in these new typologies by means of cables and tension-only rigid component leading to associate these systems with tension forces, and qualifying them of as “tension systems”.



Figure 12 Folding tensegrity ring. 2007. Motro et al.

So many papers and studies are devoted to “tensegrity systems”, which are clearly in the field of “tension structures” as described before, and so few realizations are available, that one could doubt seriously of their pertinence. This is a matter of fact that there is a “fashion” effect, but some recent developments linked with deployability and foldability are very promising. Biological systems are now well modeled with tensegrity systems, and this is an unexpected application of these new structural compositions.

If the preceding decade was clearly illustrated by designs of M. Kawaguchi, this decade is dominated by Schlaich & Bergemann’s works and realizations [30].

It is also worthy to mention the link with the activities of the Working Group on Masts and

Towers that constitute a dominant typology in the field of light structures at the beginning of this century.



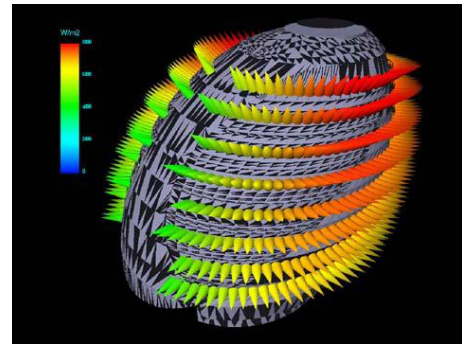
**Figure 13** Schlaich & Bergemann realizations

### 5.3 Emerging studies and conceptual design

During many years, designers were involved in an “always more” process: how to design taller buildings, domes with a bigger clear span, the highest tower etc...

Nowadays, even if these challenges are the same as before, new ideas are emerging which could be qualified with the expression “beyond and multiparametric” process.

- Beyond the classical studies: after many years of static behavior studies, dynamic ones are now undertaken (it is particularly true for our working group on “Metal Spatial Structures”), after mono material structures (concrete, wood, steel, textiles), designers are interested in hybrid structures implying new structural materials beyond classical ones: sometimes glass is now considered as a structural material.
- Multiparametric design: design no more only a problem of mechanical behavior. It can be for some specific problems, but for new projects, other constraints are taken into account, like solar aspects in free form design



**Figure 14** The solar diagram for the City Hall building.

Branko Kolarevic wrote in his paper related to “free form” that “Foster’s performative approach to the design of the City Hall building could imply a significant shift in how “blobby” forms are perceived. The sinuous, highly curvilinear forms could become not only an expression of new aesthetics, or a particular cultural and socio-economic moment born out of the digital revolution, but also an optimal formal expression for the new ecological consciousness that calls for sustainable building.” [31]. He expresses the fact that nonmaterial aspects become as important and determining as material and structural aspects: more factors have to be taken into account during the design process. The Working Group 18 on Environmentally Compatible Structures is directly implied in these new aspects.

But it is also a matter of fact that the numerical revolution has a major impact on form finding and morphogenesis of shell and spatial structures. The free form design is a matter of controversies, and we should be happy of these controversial exchanges, if beyond these different opinions on new shapes, innovative proposals come to the light. This question was addressed by M. Majowiecki during the workshop organized in Delft by the subgroup on Free Form Design (2006) [32].

The question is largely open since the first famous designs by F. Ghery, where physical and numerical models are associated.



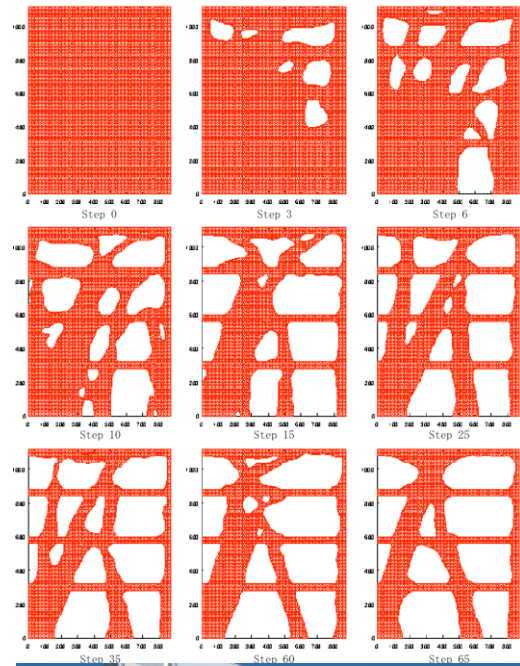
**Figure 15** *Physical Model for Guggenheim Museum. Ghery.*

Among the new numerical possibilities **Computational Morphogenesis** is a very promising one and H. Ohmori gives the following definition that he submitted for the recent sixth seminar of Structural Morphology (Acapulco, 2008) :

*“Computational morphogenesis is the word that is generally used for expressing those techniques or ways of thought by which the configuration or the system itself of the structures is generated mainly through the usage of the computers, which is realized on the firm foundation of both FEM as a tool of numerical analysis and various kinds of method based on relatively newly developed algorithms for structural optimization. Recently, it has been getting a considerable number of users such as structural engineers or engineering architects for the structural design of the actual buildings as well as the proposal for the architectural competitions”*

Besides these numerical approaches, people who attended the seminar on “Morphogenesis” (organized 2008 in Acapulco ) agreed on several conclusive ideas:

- Morphogenesis has to be understood as a dynamic process (from birth –emergence- to death -recycling) in close relation with the dynamic evolution of the environment constraints and the dynamic exchange of information.



**Figure 16** *Structural Design of Wall through Extended ESO (Akutagawa Project)*

- Shell and spatial structures are the result of a structural process, which requires to find simple rules and processes to design rich shapes, richness being different from complexity.
- Tools are not a goal, they only help us. Their evaluation regarding the morphogenesis is necessary: are Genetic Algorithms,



optimization solvers adequate for architecture, are tools from car industry appropriate for architecture ?

- Nature : exploration of the morphogenesis of natural entities in relation with their functional necessities (like insect wings) is always a source of inspiration for designers.



**Figure 17** *Free Form Design and Complexity*

#### 5.4 Examples of Spatial Structures in the fifth decade

Key words for these are examples could be declined in terms of materials (membranes, composite, glass,..), in terms of form (free form surfaces), in terms of mechanical aspects related to analysis and computation, and last but not least in terms of realization. Some few examples illustrate this decade.

##### 5.41 The Wuhu Stadium in China, 2002

This realization is described in issue 151, Vol. 47, 2006, pages 171-172. Could I get original photos for this realization ?

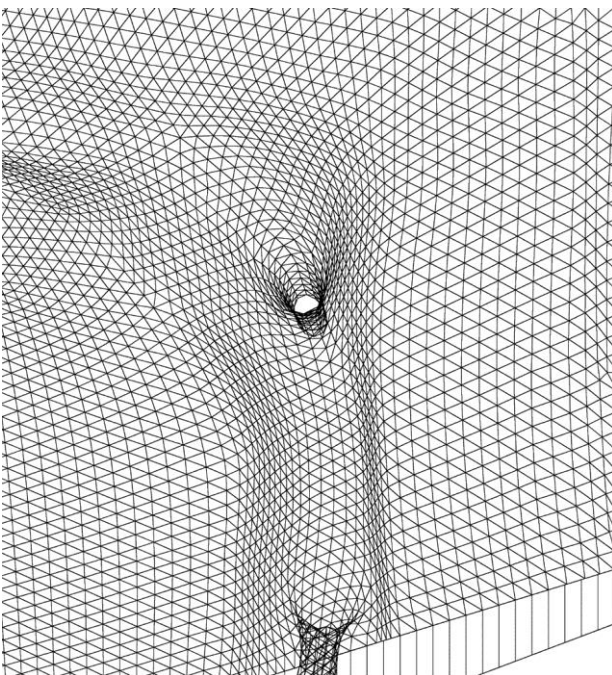
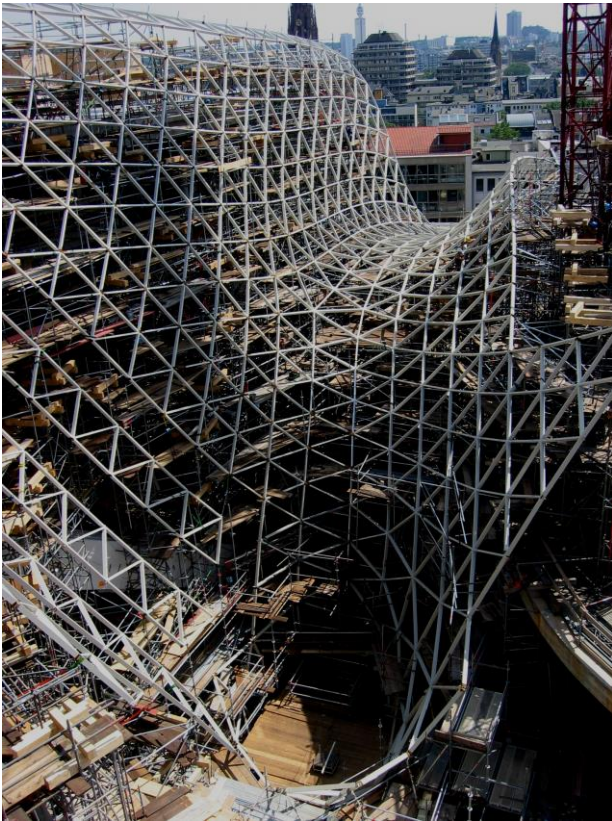
##### 5.42 The Water Cube, Beijing

I have the material for this and appropriate rights for the photos. I will make a selection and write appropriate comments.



##### 5.43 The Frankfurthochvier





I have the comments for this spatial structure. It has been presented in Bangalore (SEWC) and is part of a special Issue of IJoSS.

5.44 The world games stadium in Kaohsiung (Toyo Ito)

I will use the comments I found on the corresponding website.

## 6 CONCLUSION : IASS, THE MEETING POINT FOR DESIGNERS

The International Association for Shell and Spatial Structures has welcomed, since its foundation by E. Torroja, architects, engineers, builders, artists, mathematicians. They all contributed to the design of famous and innovative constructions. These designers may exchange their ideas during the different opportunities provided by the IASS scientific conferences that enable meetings between them and not only crossing side by side without exchanges. A real friendship has been established and transmitted for many years, and young people are clearly invited to participate to this spirit with the Hangai Prize. We can hope with confidence that after five decades this Association will be able to tackle the new challenges of the XXI<sup>o</sup> century.

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