

# Half a Century with the Space Structures Research Centre of the University of Surrey

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## Abstract

The Space Structures Research Centre was founded by Professor Zygmunt Stanislaw Makowski in 1963. The Centre is a part of the Department of Civil and Environmental Engineering of the University of Surrey, Guildford, UK. Many different activities have been organised by the Centre since its establishment in areas such as research, publication, teaching, organisation of conferences, as well as, consulting work. This paper outlines the activities of the Centre in the past 50 years and gives an overview of the role of the Centre in the development of spatial structures in the world.

**Keywords:** Space Structures Research Centre, University of Surrey, Professor Z S Makowski, Professor H Nooshin, International Journal of Space Structures, International Conference on Space Structures, Pioneers' Award in Space Structures.

## 1. Introduction

The Space Structures Research Centre was founded in May 1963 by Professor Z S Makowski and has been highly active ever since in helping to further the ideas and promote the utilisation of spatial structures. The main areas of activity encompass research to enhance the methods of analysis, design and the understanding of the behaviour of different forms of spatial structures such as domes, barrel vaults and grids, as well as structural systems such as foldable systems, towers and tension structures. Publication, teaching, organisation of conferences, besides consulting work are example of activities which the Centre has been organising. In 1971, Professor Hoshyar Nooshin was appointed as the Director of the Centre and remained in this position for 28 years. The current Director of the Centre, Professor Gerard Andrew Roger Parke, has taken the responsibility since 1998.



Figure 1: Nodus building which was donated to the Space Structures Research Centre in early 1970s, Guildford, UK. The left pictures shows the construction phase of the building [5].

In early 1970s, a building was donated to the Centre by the British Steel Corporation to use for laboratory experiments on Spatial Structures [1], Figure 1.

## 2. Research

The core aim for founding the Centre was conducting research in the design and analysis of spatial structures. A number of research students have been working on different subjects related to spatial structures in the Centre. The subjects may be categorized into Structural Morphology, Structural Analysis and Construction of different types of spatial structures including shell structures, lattice structures and foldable structures. Figure 2 gives the list of completed dissertations in the Centre since 1967. An electronic copy of some of the dissertations are available via the Surrey Research Insight Open Access [6].

	Degree	Year	First Name	Family Name	Title of Desertation
1	M Phil	1967	H	Hosseinzadeh	Analysis of Lamella Structural Systems with Particular Reference to Lamella Barrel Vaults
2	M Phil	1967	Frank E S	West	A Study of the Efficiency of Double Layer Grid Structures
3	M Phil	1970	John	Zerning	Form and Construction with Hyperbolic Paraboloidal Shells in Plastics
4	PhD	1971	Nicolas G	Kazma	Structural Behaviour and Approximate Analysis of a Double Layer Grid
5	PhD	1972	B C	Neogi	The Distribution of Bending Moments in a Flat Slab with Openings
6	PhD	1973	Usam Khairi	Bunni	Instability of Thin-walled Sections
7	M Phil	1974	A G	Collings	An Approximate Analysis of a Family of Double Layer Grids
8	PhD	1975	John Warwick	Butterworth	Nonlinear Analysis and Stability of Elastic Skeletal Systems
9	PhD	1977	M A E	Bakry	Optimal Design of Transmission Line Towers
10	PhD	1978	Alaeddin	Behravesch	A Technique for Structural Optimization
11	PhD	1979	Nasrollah	Dianat	Elastoplastic Behaviour of Flat Grids
12	PhD	1980	Mahmood	Haristchian	Formex and Plenix Structural Analysis
13	PhD	1980	Jaime S	Sanchez Alvarez	Formex Formulation of Structural Configuration
14	PhD	1981	Eysa	Salajegheh	Optimum Design of Double-layer Grids
15	PhD	1981	Chi-Wai	Wong	The Structural Behaviour of Braced Barrel Vaults with Particular Reference to Wind Effects
16	PhD	1981	Ian Martin	Collins	Collapse Analysis of Double-layer Grids
17	PhD	1982	Jan	Bobrowski	Origins of Safety in Concrete Structures
18	PhD	1984	Chukwuaka Michael	Anekwe	Reduction Method of Analysis for Dense Space Structures
19	PhD	1985	Ik Nang Anna	Hee	Plenix Structural Analysis
20	PhD	1985	Hugh Alan	Howells	Collapse Behaviour of Space Trusses with Thin-walled Members
21	PhD	1986	Philip John	Wicks	Elastic Post-buckling and Imperfection Sensitivity of Symmetric Structural Systems
22	PhD	1986	O F A	El-Labbar	Formex Graphics in Structural Analysis
23	PhD	1986	M H	Yassae	A Formex Approach to Finite Element Mesh Generation
24	M Phil	1988	Parvin D	Pakandam	Comparison of Behaviour of Three Types of Braced Domes
25	PhD	1988	Lambros	Babilis	Micro-Formian for the Analysis and Design of Space Frames
26	PhD	1988	Mohammad	Ashraf	Structural Behaviour of Composite Triple Layer Bridge Grids

27	PhD	1988	Gerard Andrew Roger	Parke	The Behaviour of Space Trusses Incorporating Novel Compression Members
28	PhD	1989	Mehdi	Mohammadi Khabbazan	The Renection Method for the Analysis of Space Frames
29	PhD	1989	Peter Lawrence	Disney	The Programming Language Formian
30	PhD	1990	Wenxiao	Shan	Foldable Space Structures
31	PhD	1990	Jackson Araali	Mwakali	The Collapse Behaviour of Double-layer Space Trusses Incorporating Eccentrically Loaded Tee-section Members
32	PhD	1990	Barbara Helen	Johnson	Near-coincident Boubly-symmetric Behaviour and Imperfection Sensitivity
33	PhD	1992	Walid S	Shatila	Computer Analysis, Design and Draughting of Semi-rigid Bolted Connections
34	PhD	1993	Chiaki	Yamamoto	New Formian and Epilanguages for Preprocessing of Space Structures
35	PhD	1993	Deepali	Hadker	Formex Configuration Processing for Space Structures
36	PhD	1993	Dimitra Christos	Tzourmakliotou	Computer Aided Design of Braced Domes
37	PhD	1994	Eltayeb Elrayah	Khalafalla	Computer Aided Processing of Geodesic Structural Forms
38	M Phil	1994	Hiroyuki	Tomatsuri	Space Structure Forms and Analysis
39	PhD	1997	Oliver Charles	Champion	Polyhedric Configurations
40	PhD	1997	Karim	Abedi	Propagation of Local Instability in Braced Domes
41	PhD	1997	Mohammad Reza	Chenaghloou	Semi-rigidity of Connections in Space Structures
42	PhD	1999	Isabell S	Hofmann	The Concept of Pellelevation for Shaping of Structural Forms
43	PhD	1999	Fevzi	Dansik	Force Density Method and Configuration Processing
44	PhD	2000	Yoshihiko	Kuroiwa	Regularisation of Structural Forms Using Genetic Algorithms
45	PhD	2000	Mohammad Ali	Saeedi	An Approximate Method for the Prediction of the Behaviour of Some Space Structures
46	PhD	2000	Olivier L S	Baverel	Nexorade: a Family of Interwoven Space Structures
47	PhD	2001	Graham	Barnard	Engineering with Small Roundwood - its Mechanical and Physical Characteristics
48	PhD	2002	Hossein	Ebrahimi Farsangi	Topological Optimisation of Double Layer Grids Using Genetic Algorithm
49	PhD	2002	Arjang	Sadeghi	Equivalent Earthquake Loads for Some Families of Barrel Vaults
50	PhD	2002	Mauro	Overend	The Appraisal of Structural Glass Assemblies
51	PhD	2004	Sana Said	El-Lishani	Cable Domes and Their Stability
52	PhD	2004	Mohammad Hadi	Pashaei	Damping Characteristics of Mero-type Double Layer Grids
53	PhD	2004	Mohammad Reza	Davoodi	Effects of Bolt Tightness on the Behaviour of Mero-type Double Layer Grids
54	PhD	2004	Xenofon	A.Lignos	A Contribution to the Nonlinear Stability Analysis of Multiple Parameter System
55	PhD	2006	Mahdi	Moghimi	Formex Configuration Processing of Compound and Freeform Structures
56	PhD	2006	Douglas William	Brown	Verifying the Correctness of Structural Engineering Calculations

57	PhD	2007	Karl-Heinz	Friedrich Stech	Efficiency of Bridge Structures
58	PhD	2008	Pierre	Farrugia	Kinematic Analysis of Foldable Structures
59	PhD	2009	Masoud	Bolourian	Theory of Plenices
60	PhD	2012	Akbar	Rahimi Noshnagh	Suspen-domes: Study of the Behaviour and the Design

Figure 2: List of the completed M Phil/PhD dissertations in the Centre.

A new algebra, namely, formex algebra, and its accompanying programming language Formian were developed for configuration processing of spatial structures. The early work in formex configuration processing in the seventies was greatly helped by substantial donations from a group of Iranian Engineers, Figure 3. These are A. Sarshar, A. Jahanshahi, C. G. Abkarian, G. A. Mirzareza, M. S. Yazdani and J. Hassanein. Also, during the nineties, the Taiyo Kogyo Corporation of Japan, NASA (Award No NAGW-4132) and the Tomoe Corporation of Japan were instrumental in supporting research in formex configuration processing.



Figure 3: Some of the donators are seen in the picture. From left: A. Sarshar, M. S. Yazdani (H Nooshin and M Ghalibafian), C. G. Abkarian, G. A. Mirzareza and A. Jahanshahi [5].

### 3. Publications

Over the years the Centre has been responsible for the publication of a number of books, papers and conference proceedings. In particular, the Centre was involved in the publication of the International Journal of Space Structures since 1985.

#### 3.1. Books

The following nine books, which are valuable references in the field of spatial structures, have been published by the Centre:

Makowski Z.S., *Räumliche Tragwerke aus Stahl*. (1st ed. in German), Verlag Stahleisen m.b.H., 1963.

Makowski Z.S., *Constructions Spatiales en acier*. (1st ed. in French), Verlag Stahleisen m.b.H., 1963.

Makowski Z.S., *Steel Space Structures*. (1st ed. in English), Verlag Stahleisen m.b.H., 1964.

Bunni U.K., Disney P. and Makowski Z.S., *Multi-layer Space Frames*., Constrado, 1980.

Makowski Z.S., *Analysis, Design and Construction of Double Layer Grids*., Applied Science Publishers LTD, 1981.

Nooshin H., *Formex Configuration Processing in Structural Engineering*., Elsevier Applied Science Publishers LTD, 1984.

Makowski Z.S., *Analysis, Design and Construction of Braced Domes*., Granada Publishing, 1984.

Makowski Z.S., *Analysis, Design and Construction of Braced Barrel Vaults*., Elsevier Applied Science Publishers LTD, 1985.

Nooshin H., *Studies in Space Structures*., Multi-Science Publishing Company Limited, 1987.

#### 3.2. International Journal of Space Structures

The first issue of the International Journal of Space Structures was published in 1985. According to the Editorial Note by the founders and initial editors of the Journal, Z S Makowski and H Nooshin, 'the need for a journal dealing specifically with space structures was felt long before the recent International Conference on Space

Structures, which was held at the University of Surrey in September 1984. The success of the conference reinforced the belief that the time was now ripe for the launching of a journal on space structures.' Twenty one years later, in 2006, Rene Motro and John Chilton were appointed as the new editors of the Journal. Later on in 2008, Motro carried on with the editorship alone. In 2012, he decided to focus on his position as the president of the International Association for Shell and Spatial Structures, so he passed the responsibility of the editorship to Olivier Baverel and Bernard Maurin. The Journal has published 28 special issues on specific subjects, Figure 4. The figure gives information about these special issues including the subject and the name of the Guest Editor(s).

Vol	No	Year	Subject of the Special Issue	Guest Editor(s)
5	3 & 4	1990	Geodesic Forms	Tibor Tarnai
7	4	1992	Stability of Space Structures	Victor Gioncu
8	1 & 2	1993	Deployable Space Structures	Sergio Pellegrino
10	3	1995	Prefabricated Spatial Frame Systems	Ariel Hanaor
11	1 & 2	1996	Morphology and Architecture	Haresh Lalvani
12	3 & 4	1997	Dynamics of Space Structures	Yasuhiko Hangai
14	2	1999	Form Finding of Tension Structures	Rene Motro
14	3	1999	Aircraft Hangers	G. S. Ramaswamy
15	3 & 4	2000	Topics in Design of Lattice Structures	Ariel Hanaor
16	3	2001	Space Structures in China	Tien T Lan & S. Z. Shen
17	2 & 3	2002	Teaching of Space Structures	John Chilton
21	1	2006	The Pioneers of Space Structures	-----
22	1	2007	Footbridges	Enzo Siviero
22	3	2007	Adaptable Structures	Arno Pronk
23	4	2008	Tensioned Membrane Construction	Marijke Mollaert & John Chilton
24	2	2009	Structural Engineers World Congress	R. Sundaram
24	4	2009	Structural Membranes: Analysis and Design	Eugenio Oñate
25	2	2010	Computation of Spatial Structures	John F. Abel
26	3	2011	Celebrating 25 Years Devoted to Space Structures	-----
26	4	2011	Reciprocal Systems	Olivier Baverel
27	2 & 3	2012	Tensegrity	Gian Carlo Giuliani
28	3 & 4	2013	Active Bending	Christoph Gengnagel

Figure 4: List of the special issues of the International Journal of Space Structures including the subjects and the guest editor(s).

#### 4. Teaching

The Centre has been active in offering courses on spatial structures at various levels during the past 50 years. Specifically, a course entitled 'Space Structures' for postgraduate students of the University of Surrey has been designed and delivered since 1964. The Centre has organized a celebration on the occasion of the 50<sup>th</sup> year of teaching the course by Prof H Nooshin on 25 March 2013, Figure 5. Also, various workshops and short courses at different levels have been organised by the Centre in the UK and other countries including Australia, China, India, Iran, Japan and Romania. Figure 7, for instance, shows a group of primary school students, during a one day workshop on 'basics of form generation in Formian' in the University of Surrey, UK. Another example of the many teaching activities is a two week course on spatial structures. The course was organised for its 19<sup>th</sup> time in April 2014 at the University of Kerman, Iran. Figure 8 shows a group of attendees of the course in 2001.



Figure 5: A celebration on the occasion of 50<sup>th</sup> year of teaching Spatial Structures, 25 March 2013 [5].



Figure 6: A caricature of Prof H Nooshin by one of his placement year students during a regular visit [5].



Figure 7: A group of primary school students at the Centre, during a one day workshop on 'basics of form generation in Formian' [5].



Figure 8: Some attendees of the two week course on spatial structures in the University of Kerman, Iran, 2001 [5].

## 5. Conferences

A series of International Conferences on Space Structures has been organised by the Centre, the first of which was in 1966. The last conference in this series was combined with an IABSE-IASS event in London, 2011. The proceeding of the first conference, held in 1966, edited by R M Davies, the second one in 1975, edited by W J Supple, the third one in 1984, edited by H Nooshin, the fourth one in 1993, edited by G A R Parke together with C M Howard and the fifth one in 2002, edited by G A R Parke and P Disney. These proceedings are recognised as major contributions to the development of space structures technology and architecture. The first conference brought over 700 participants from 44 countries, the second, some 400 engineers from 51 countries, the third one over 500 engineers and architects from 63 countries, the fourth, some of 400 participants and the fifth one over 400 engineers and architects. Figures 9 and 10 show two memorial gifts to the Centre given by the Mero Company and the British Aluminium Company on the occasions of the Second and the Third International Conferences, respectively.

Also, the Centre was involved in organising a number of seminars in association with other organisations. Figure 11 shows one of such seminars on formex algebra and Formian, Osaka, Japan, 1990.



Figure 9: A 10m height Steel memorial gift by the German Mero Company on the occasion of the Second International Conference on Space Structures, University of Surrey, September 1975 [5].



Figure 10: A 6m diameter aluminium dome, a gift from the British Aluminium Company on the occasion of the Third International Conference on Space Structures, University of Surrey, September 1984 [5].

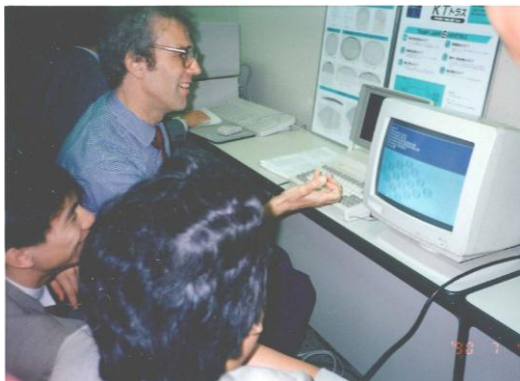


Figure 11: A seminar on formex algebra and Formian, Osaka, Japan, 1990. The left picture shows Dr Peter Disney demonstrating the initial version of Formian in the conference [5].



### 5.1. Pioneers' Award

It has been a tradition of the Space Structures Research Centre to recognise and honour those who have made significant contributions in the field of spatial structures. This has been done through a special award called the "Pioneers' Award", given during the International Conferences on Space Structures held at the University of Surrey. List of the recipients of the Pioneers' Award is given in Figure 12. Also, two examples of the Award are presented in Figure 13.

The Third Conference in 1984	The Fifth Conference in 2002
Francisco Castano (Mexico)	Michael Burt (Israel)
Stephane du Chateau (France)	Mick Eekhout (Netherlands)
H G Fentiman and A E Fentiman (Canada)	Felix Escrig (Spain)
Fujio Matsushita (Japan)	J Francois Gabriel (USA)
Max Mengerhausen (Germany)	Victor Gioncu (Romania)
Donald L Richter (USA)	Kajal K Gupta (USA)
Yoshikatsu Tsuboi (Japan)	Ariel Hanaor (Israel)
	Kazuo Ishii (Japan)
The Fourth Conference in 1993	Shiro Kato (Japan)
Jan Bobrowski (UK)	Haresh Lalvani (USA)
David G Emmerich (France)	M Majowiecki (Italy)
Yasuhiko Hangai (Japan)	Stefan J Medwadowski (USA)
Yoshito Isono (Japan)	Rene Motro (France)
Mamoru Kawaguchi (Japan)	Sergio Pellegrino (UK)
Tien T Lan (China)	Ekkehard Ramm (Germany)
Lewis C Schmidt (Australia)	Masao Saitoh (Japan)
Mircea V Soare (Romania)	Jorg Schlaich (Germany)
Ronald G Taylor (UK)	Tibor Tarnai (Hungary)

Figure 12: List of the Pioneers’ Award recipients given during the International Conferences on Space Structures.

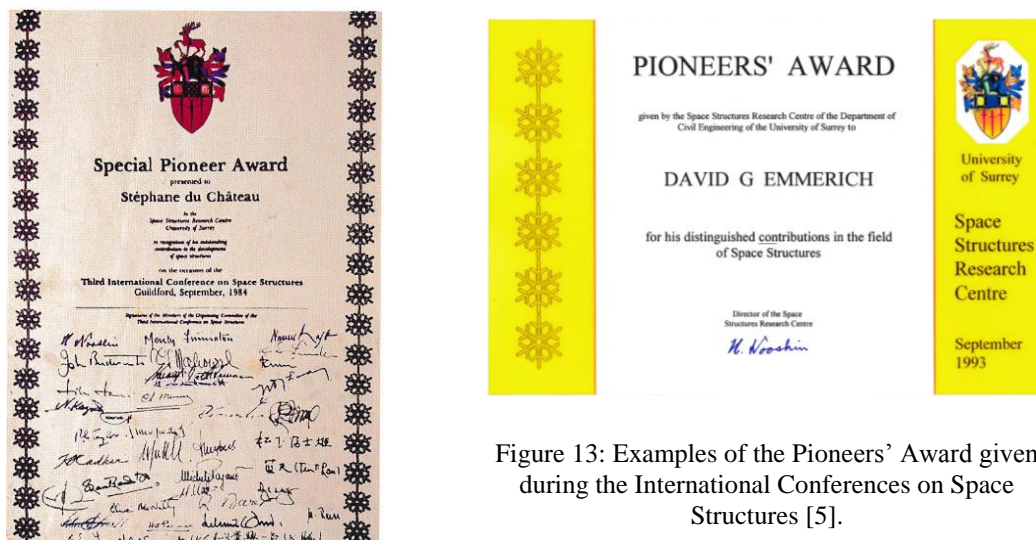


Figure 13: Examples of the Pioneers’ Award given during the International Conferences on Space Structures [5].

## 6. Contributions to the industry

A number of firms, specialised in spatial structures, have been in close relation with the Centre. The technical staff of the firms, as well as the managers, have been sent to the Centre to expand their knowledge. These include the famous Japanese firms of Taiyo Kogyo Group and Tomoe Corporation. Figure 14 shows an annual gathering of the “Surrey Club” at the Taiyo Kogyo Company, Tokyo, March 1993. Also, consulting work has been carried out in the Centre including the design of the Jumbo Jet Hangars at London Heathrow Airport, Figures 16, and the prestressed cable roof of the Farahabad (Takhti) Sports Stadium in Tehran, Figure 17.





Figure 15: Annual gathering of the "Surrey Club" at the Taiyo Kogyo Company, Tokyo, March 1993 [5].

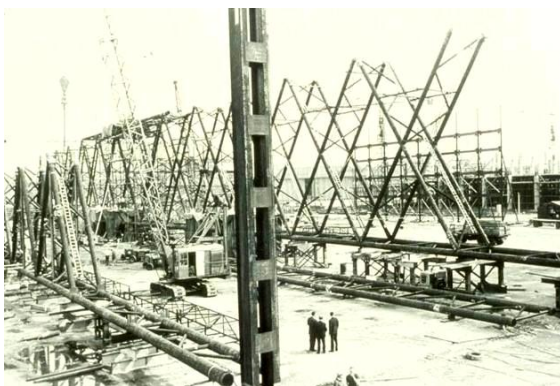


Figure 16: Spine girder and fascia girder of the Jumbo Jet Maintenance Hangar 01 at Heathrow Airport during the construction, London, UK, 1969 [5].



Figure 17: Takhti (Farahabad) Sports Stadium in Tehran, Iran, opened in 1974, photo by Omidali Samavati [4]

In 2014, the Research Centre is still continuing with its strong commitment into understanding further structural morphology, as well as the behaviour of spatial structures with over 10 PhD students engaged in this work.

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