WANDA J LEWIS

Dr Wanda J Lewis is an Emeritus Professor in the School of Engineering at the University of Warwick, UK. She is a Chartered Civil Engineer and a Fellow of the Institution of Civil Engineers (ICE). In 2020, she was awarded a Fellowship of the Royal Society of Arts (RSA) for her work on novel approaches to engineering design and contributions to the working environment. This was followed by an Emeritus Fellowship by The Leverhulme Trust to study form-finding of natural forms of arches.

Wanda has more than 30 years of research experience and is a pioneer in the development of form-finding methods defining optimal shapes of structures characterised by a minimal material usage and minimal stress. In preparation of this article, we had a friendly conversation with Wanda about her early life experiences and life interests.

Wanda was born in Zielona Góra (green mountain), Poland, in 1951 (Fig. 1). She has two brothers, known by the name Grabowski, who live in Poland; the younger is an entrepreneur, and the older is a retired academic specialising in the design of heavy machinery. Both are innovators with a number of patents to their names in electronic and mechanical systems. Wanda has always been very competitive with her older brother and believes this is the reason she followed an engineering career path.

Wanda grew up in Opole (Fig. 1), in the south-west corner of Poland on the Odra River, where her parents moved when she was a baby. The town is located near the border with the Czech Republic; it used to be a German territory before WWII. Her parents were among the first settlers in Opole, when it became part of Poland. The town was rebuilt after the war and it is now a beautiful place. Wanda remembers

Fig. 1 Zielona Gora and Opole in Poland

the abundance of green areas and wonderful cafes selling the most scrumptious cream cakes and ice creams. In particular, she remembers getting excited every year at the annual National Festival of Polish Song, when celebrities from the musical world arrived in Opole. During her early childhood, she recalls a strong animosity between Polish and German speaking populations; however, she says, their differences disappeared with time. After the war, Poland was a police state for many years, but the poverty experienced during and after the war brought people together. There was very little crime, because of the strong sense of community and people's willingness to help each other. Education was the top priority for all. Although living under a communist regime until the 70s, Wanda had access to foreign newspapers and a first-class cinema, where she learned about the freedoms enjoyed by people living in the West. This made her want to be free to travel, see new places, and experience new influences.

Having obtained a diploma in economics and a civil engineering degree in Poland, Wanda moved to the UK in 1975. She completed an MSc degree in Foundation Engineering at the University of Birmingham in 1976. Shortly afterwards, she started her part-time PhD in structural engineering at the University of Wolverhampton, specialising in tension cable roofs (1976-1982). In 1983, she began working as a Graduate Structural Engineer at the Dudley Metropolitan Borough Council. Her first major project was Hurst Primary School near Wolverhampton, built on reclaimed land. To begin with, she worked on the project under the supervision of a senior engineer but, by 1985, she was responsible for the entire structural content of the building. Wanda's longing for academic life brought her to the University of Warwick in 1986, where she is currently based.

CONT.

Wanda has a daughter (born in the UK) who used to practice as a doctor but is now working as a public health consultant. Wanda's daughter married a very talented Jaguar engineer/technical specialist and they have an eight-year-old son who is passionate about mechanical systems. Some of his teachers call him a 'little engineer' and Wanda observes his development with a great deal of fascination.

Wanda's personal interests include cinema, politics, DIY, and crafts. She also appreciates good art and is a strong supporter of **Mariusz Dudek**, a very talented artist from Cracow, Poland. Mariusz portrays beauty in time-won objects and has recently developed a passion for exploring a relationship between art and music. Music offers a dialogue between various instruments, or - as in the case of Lutosławski's cello concerto - tension between the leading instrument and the rest of the orchestra. Mariusz discovered that similar emotions and relationships can be expressed through painting (Fig. 2 and Fig. 3). The latest series of his silkscreen graphics, entitled *Chaconne*, is a tribute to Johann Sebastian Bach and his Partita No 2 in D minor for solo violin (Fig. 4). Wanda and Mariusz often discuss sources of inspiration for their respective works, which they see as being linked by separate form-finding themes: 'music and art' and 'nature and design'.

In our interview with Wanda, she tells us about inspirational figures in her field who have had a strong influence on her career. Her true inspiration to research structural forms originated from meeting Frei Otto, Heinz Isler, and Hoshyar Nooshin; she became fascinated with Otto and Isler's philosophy of design based on form-finding experiments, and Nooshin's mathematical and computational talent for shaping spatial structures.

Fig. 2 Aleatoric Composition (left), inspired by Lutoslawski; Melanomic (right). Oil on canvas by Mariusz Dudek

Fig. 3 A Cellist (inspired by Shostakovich). Oil on canvas by Mariusz Dudek

Fig. 4 Chaconne (inspired by Bach), silkscreen by Mariusz Dudek

RESEARCH AND INDUSTRY CONTRIBUTIONS

Wanda's research is in the area of form-finding. For many years she studied computational form-finding methods applied to tension fabric structures, and this work culminated in her monograph **'Tension Structures: Form and behaviour'**, first published in 2003, with the second edition appearing in 2018 [1]. The book advocates the use of the constant stress principle observed in natural objects such as soap films, and can be used as a tool for shaping optimal (minimal) forms of cable net and membranes structures. Apart from cable nets and fabric roofing forms, the book discusses suspension bridge cables and the relevance of their shape to modelling optimal forms of arch structures. It also illustrates a number of practical projects, including Wanda's favourite spatial structures worldwide, i.e. shading umbrellas in Madinah (Medina), Saudi Arabia, which feature on the cover of her book (Fig. 5). She says these umbrellas are extremely delicate, aesthetically pleasing, and beautifully designed using the principle of constant stress.

Besides her research into natural structures for architectural application, Wanda has also been involved in automotive and aerospace research, in collaboration with Jaguar Cars and Rolls-Royce. In one of her projects, the **convertible roof for the Jaguar XK8**, she investigated the effect of the aerodynamic loading on the safety of the car hood and its deformation under the full speed of the car (Fig. 6). She also led research projects in collaboration with a number of European companies on the design of minimal surface membranes. Fig. 7 shows a prototype of a constant stress membrane constructed as part of a European project in which her main collaborators were SL Rasch (Germany), Canobbio (Italy), and ESI (France). Wanda was also a principal investigator on a multi-disciplinary project **'Designing for the 21st Century'** in collaboration with the Courtauld Institute of Art in London, where she studied mechanical properties of artist canvas with a view to informing the work of art conservators.

Currently, Wanda's research concerns a development of analytical form-finding methods applied to rigid structures, such as arch bridges, as described in her paper **'Mathematical model of a moment-less arch'** [2]. One of the conclusions of the work is a comparison between the material volume used in a moment-less (form-found) arch, as opposed to that found in conventional parabolic and circular forms, as shown in Fig. 8. She recently secured a grant from the Leverhulme Trust to work on the project 'Analytical form-finding applied to arch structures'. See a list of her **publications**.

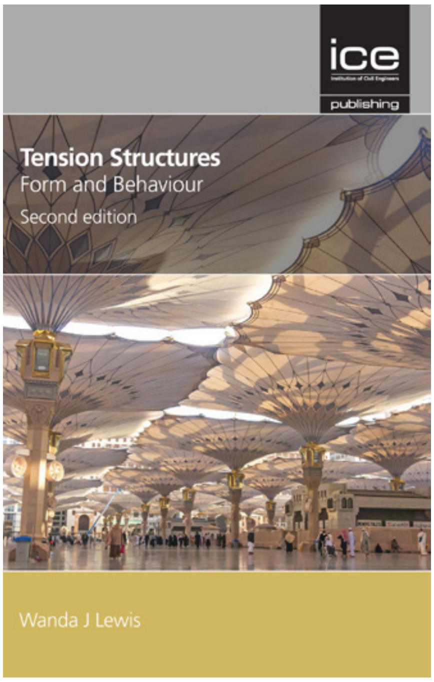

Fig. 5 Cover of Wanda's book: Tension Structures

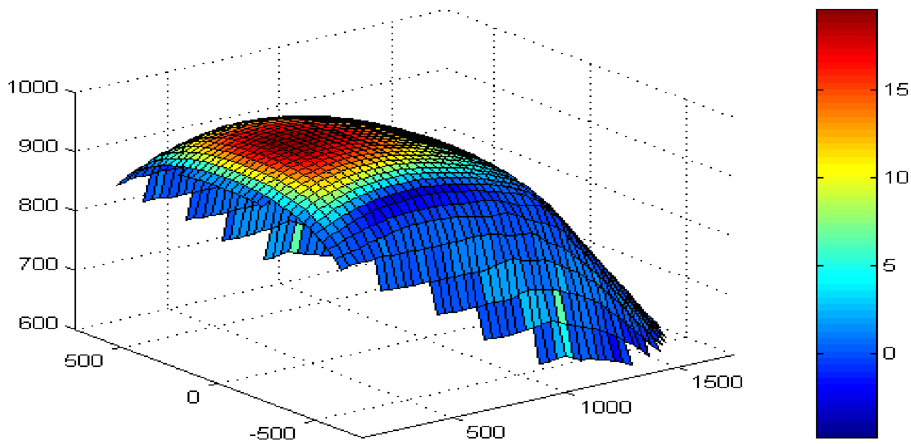

Fig. 6 Deformed Jaguar hood shape with shading indicating vertical displacement in mm.

Fig. 7 Tension membrane designed as a constant stress structure. European project in collaboration with SL Rasch, Canobbio, and ESI; on location in Milan, Italy

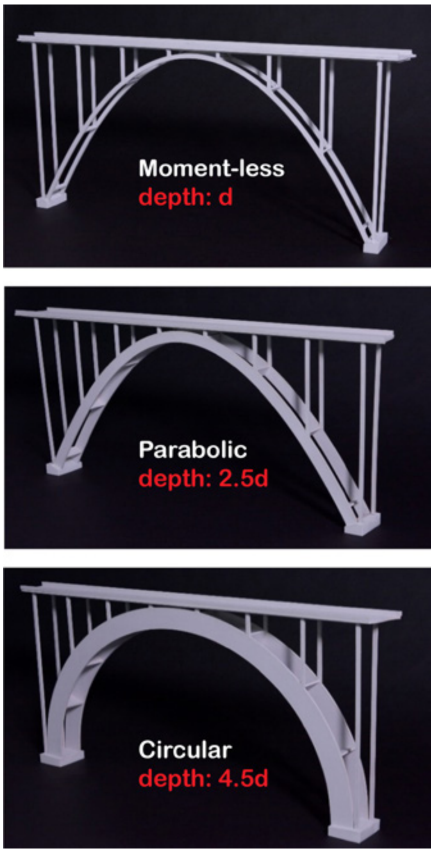

Fig. 8 An illustration of the amount of material required in parabolic and circular arches to match stresses in the moment-less arch

CONTRIBUTIONS TO EDUCATION

Wanda has been actively engaged in teaching since joining the University of Warwick in 1986. In 2016 she was awarded emeritus professor status and since then has been involved mainly in research activities, with the exception of being a project consultant/adviser to students. During her career, she has taught a range of subjects including mathematics, statistics and numerical methods, mechanics, structural analysis, concrete structures, and design.

In 1998, with the help of Heinz Isler who acted as her mentor, Wanda set up a new teaching course at the University of Warwick on three-dimensional structural forms. Fig. 9 shows examples of some of the early work by the students on this course.

She ran the course together with Professor John Chilton from the University of Nottingham. Prof Chilton, who is a great admirer of Heinz Isler, wrote the book *Heinz Isler – The engineer's contribution to contemporary architecture* [3].

Fig. 9 Students studying 3D structural forms and their models

INTERVIEW

We had the opportunity to interview Wanda in September 2020. She tells us about the lockdown, her career journey, her experience working with industry partners, meeting Professor H Nooshin and Professor Z S Makowski, and her research in tension structures and form-finding. She also highlights the importance of involving young people in creating physical models, in order to gain instantaneous insight into the behaviour of structures. Below is a brief account of **Wanda's interview.**

Wanda tells us that the one positive thing about lockdown has been having a bit more time to spend in the garden, but overall, she does not like physical separation from family and friends. Even before Covid-19, Wanda was concerned about the dehumanising effect information technology has on us.

As mentioned, Wanda began working at the University of Warwick in 1986. She tells us that a critical point in her career came a year later, in 1987, when she attended a presentation delivered by Siegfried Gass from the Institute of Lightweight Structures in Stuttgart on 'minimal structures by analogy to nature' at a conference on Non-Conventional Structures in London. She found his presentation mesmerising. The year after, Wanda was invited to Stuttgart, where she met Frei Otto. She says that she could see the charisma of the great man and how influential he was in leading a huge research programme on form-finding. She recalls that, on the very first day, he came to her and said: 'Remember, the most important thing is to get the shape of the structure right; the rest can be left to engineering calculations.' Wanda remained friends of the Institute and visited it many times afterwards.

Wanda joined the International Association of Shell and Spatial Structures (IASS) in the early 90s, where she met a number of inspirational people, including Heinz Isler (Switzerland), who was famous for his aesthetically pleasing and durable shell structures. Isler was like a mentor to Wanda, an helped her to set up a new teaching course on three-dimensional forms (Fig. 9).

Wanda tells us that she is currently developing analytical form-finding techniques, and gave us a concise account of her research journey in the section 'Your Space, Your Structure', illustrated by some examples of the different types of structures whose optimal geometry can be found using different form-finding methods. She has a vast experience in tension structures and explains how these are the key to understanding the topic of form-finding. She describes form-finding as 'a process of shaping structures by the forces developing in them' and describes the different types of form-finding methods, which she groups into physical, computational, and analytical modelling – her latest area of research. She points out that the main physical modelling techniques include soap films and inverted hanging models. She also tells us that computational and analytical methodologies complement physical modelling, producing a more accurate description of the surface geometry, and that when used interactively, they become very powerful tools in designing aesthetically pleasing and durable structures.

Wanda highlights the Institute of Lightweight Structures (now ILEK) in Stuttgart, which she says was also referred to as Frei Otto's Institute. This is one of the early examples of tension structures designed using soap film models/analogy. Figure 10 shows the interior of the Institute comprising a cable net structure and rigid cladding. She also presents more recent applications of the constant stress principle in minimal design such as the 250 **convertible umbrellas** in Madinah, Saudi Arabia, spanning 26 x 26m (shown on the cover of her book in Fig. 5) – a project completed in 2011, and the largest convertible umbrella prototype spanning 53 x 53m in the Grand Mosque in Makkah (Mecca) in Saudi Arabia, completed in 2015 (Fig. 11). Both structures were designed by SL Rasch who takes Frei Otto's vision of 'minimal architecture' forward.

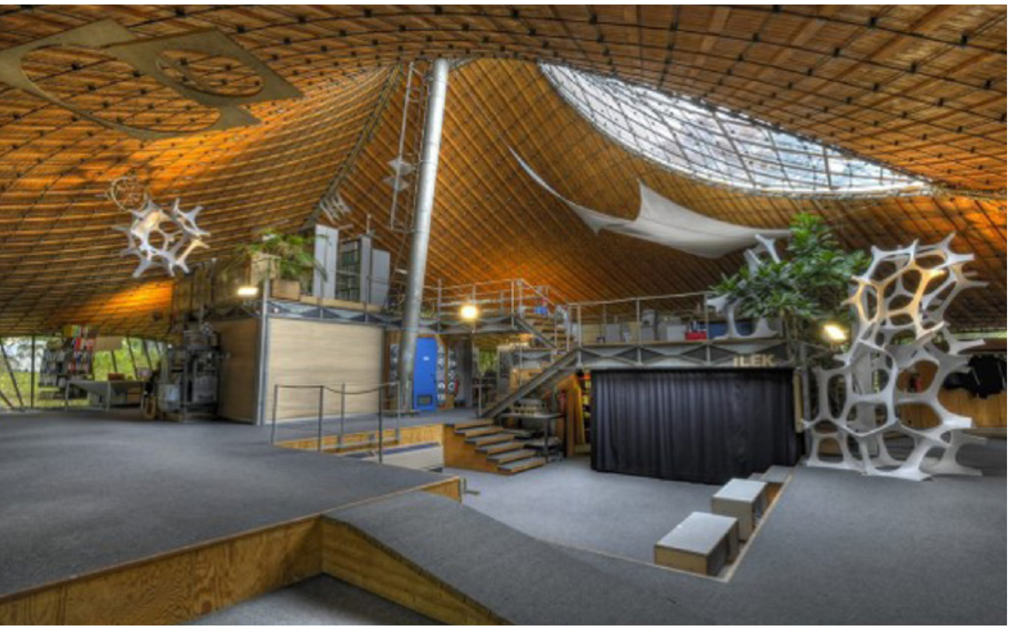

Fig. 10 Interior view of the Institute of Lightweight Structures and Conceptual Design (ILEK) Stuttgart, Germany

INTERVIEW CONT.

Wanda also shows us some of the shell structures designed by Heinz Isler, like the Petrol station in Deitingen in Switzerland spanning 30m with only 80mm in shell thickness shown in Fig. 12. She explains that these are examples of experimental form-finding involving inverted hanging models in which the shape of a shell represents an upside-down form of a hanging piece of fabric supported at the corners. These structures have a span/ depth ratio of over 300 - unthinkable in conventional design. Yet, they do not leak or crack by the virtue of their form-found shape. She also shows us some examples of constant stress (minimal) surface membranes whose shape is generated using computational form-finding and Formian as an interface (Fig. 13). Formian is a computer software, a pre- and post-processing tool developed by Prof Nooshin at the University of Surrey that allows easy manipulations of 3D geometries of spatial structures [4].

Fig. 11 Prototype of the largest umbrella in the world for the Grand Mosque in Makkah, Saudi Arabia

Fig. 12 Petrol station in Deitingen, Switzerland, 1968, designed by Heinz Isler

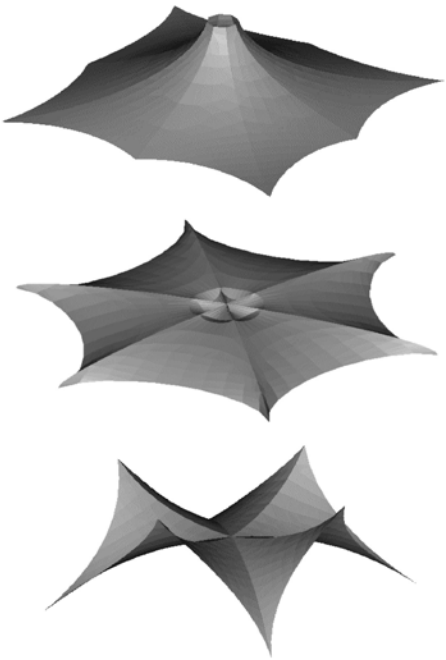

Fig. 13 Minimal surface membranes, generated using computational form-finding and Formian as an interface

SOME RELEVANT LINKS

Spatial Structures; Movers and Shakers – with Wanda Lewis

Professor Wanda Lewis's profile on the University of Warwick website

Female Engineer elected a Fellow of the Royal Society of Arts

REFERENCES

[1] W. Lewis, Tension Structures: Form and behaviour, Second edi, 2018. https://www.icebookshop.com/Products/Tension-Structures-Form-and-behaviour,-Second-edit.aspx

[2] W. Lewis, Mathematical model of a moment-less arch, Proc. R. Soc. A. 472 (2016). https://doi.org/https://doi.org/10.1098/rspa.2016.0019

[3] J. Chilton, A. Macdonald, R. Pedreschi, Heinz Isler - The engineer's contribution to contemporary architecture, Thomas Telford, London, 2000.

[4] H. Nooshin, O. Samavati, A. Sabzali, Basics of Formian-K, 2016. https://www.researchgate.net/publication/315809195_Basics_of_Formian-K

* Note that web addresses from the 'some relevant links' section and from hyperlinks were accessed on September 2020.