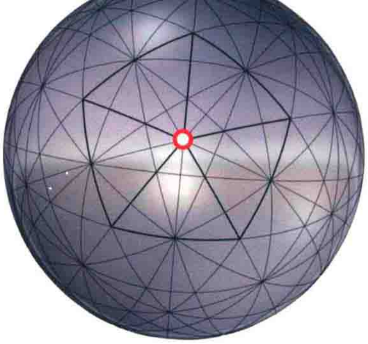
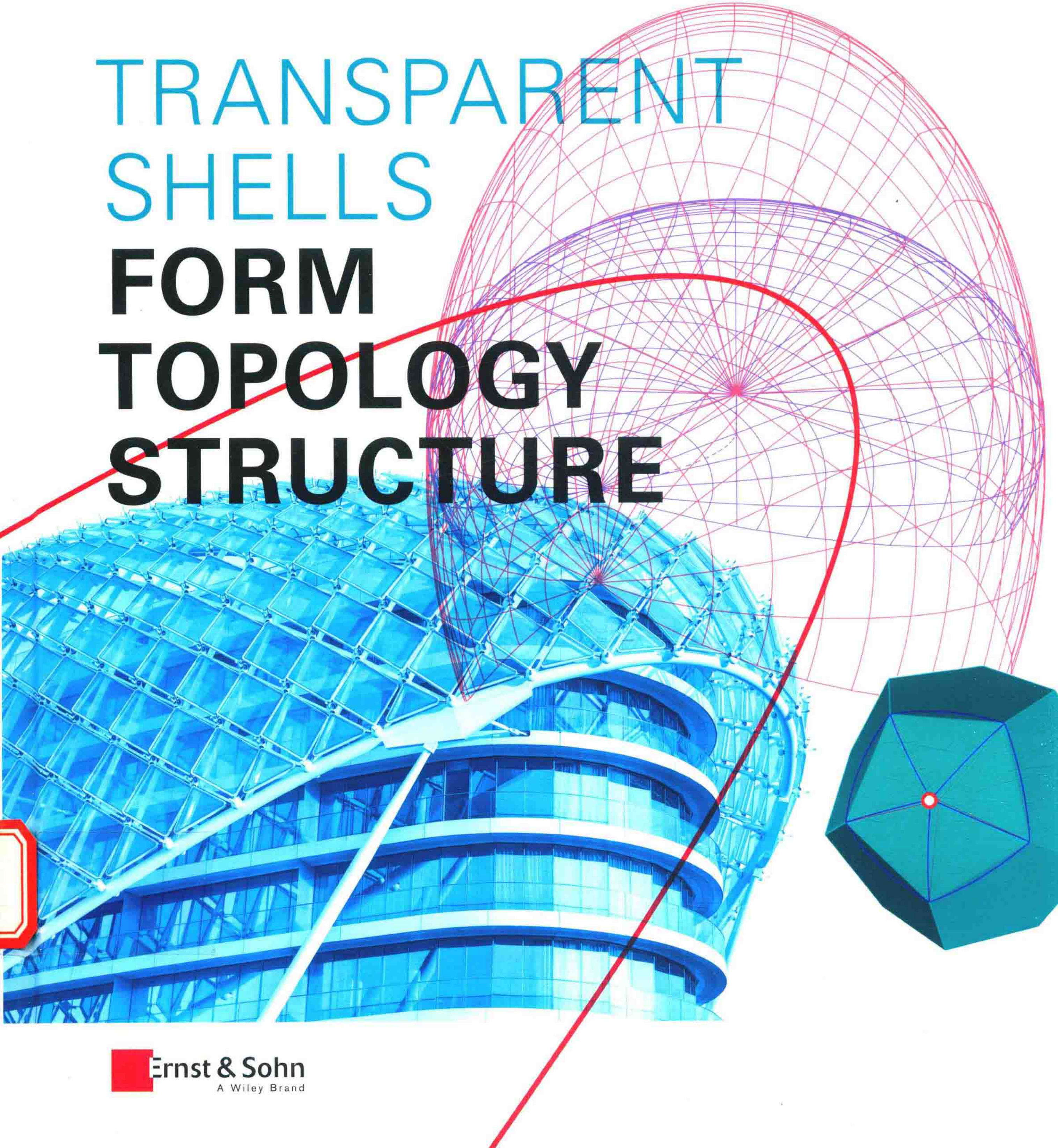
Hans Schober



TRANSPARENT SHELLS
FORM TOPOLOGY STRUCTURE



Ernst & Sohn
A Wiley Brand

Hans Schober

TRANSPARENT SHELLS
FORM TOPOLOGY STRUCTURE

Ernst & Sohn
A Wiley Brand

Foreword

This book describes a specific, but beautiful, building design: the glass grid shell for large-span, double-curved glazed roofs with minimal structural weight and ingenious details.
Skilfully and diligently the description encompasses the whole range, from grid shells with flat quadrilateral meshes to freeform domes and the optimization of their shape, structure and construction, supported by many examples taken from the author's practical experience.
This book is aimed mainly at structural engineers. It introduces them to a new and attractive yet challenging field with which they can approach not only architects but also clients. It therefore opens up a whole range of opportunities to structural engineers, thanks not least to the many examples featured, including one of the first applications of this design principle which was applied in the roof of Munich's Olympic stadium in 1972.
So I, who was fortunate to share an office with the author for many years and facilitate this development, can only welcome this multifaceted book with open arms and recommend it eagerly, in the certain hope that it will stimulate creative engineers to build other appealing structures using lightweight, elegant glass grid shells.

Jörg Schlaich
Berlin, May 2015

Preface

In the 1980s, technological development inspired the construction of single and double-curved glass buildings. The development of powerful computers and CAD programs, combined with CNC machines meant that geometrically complicated structures also became competitive. This led partly to a type of architecture that was unshackled, to "blob architecture" or organic, free-form architecture. Designing completely free forms requires special skills which very few designers possess, since only in the rarest cases are opulent and undisciplined "blobs" good architecture. Building design can only be called great architecture when an appealing appearance goes hand in hand with a clear functional design that is fit for its purpose. The building's visual appearance should be seen as an integrative part of the technical development.
During this period, the offices of schlaich bergermann und partner in Stuttgart developed grid shells: an innovative supporting structure that used prestressed cables to convert the supporting framework into a single-layer shell structure that is suitable for single and double-curved shapes.

This book is by no means exhaustive but in it I have set down my thoughts and experience regarding the development of these transparent shells; experience gathered since that time to the present in the offices of schlaich bergermann und partner sbp.
I owe a dept of gratitude to my teacher and longtime "boss" Jörg Schlaich for providing a creative, open environment in the office which made it possible for me to participate in interesting and innovative developments and to lead a fulfilling professional life.

The graphic design principles for grid shells, which are simple, clear and easy to understand and can readily be applied using the currently available modules of customary CAD programs, take up a significant proportion of the book.
There are now computer tools available that generate grids with the desired properties on unmeshed, completely freeform surfaces, thus producing homogeneous structures. Whilst this would be impossible without this software, I do believe that simple, understandable principles, whose basic mathematical and geometric concepts can be reconstructed and which therefore do not constitute a black box, still have their place. The mathematically based shapes are "justified" and disciplined, and mathematical relationships have their own inherent aesthetics. Rational design principles are timeless.
That which is understandable is usually perceived as good or right – this applies to both the geometry and the distribution of forces. With reference to the famous statement about good theory, Jörg Schlaich said it in a nutshell: "There is nothing more practical than a transparent theory."

In Chapter 5, I confine myself to brief notes on the use of complex programs for generating (geometric) grids on free forms. The simple graphic design principles of Chapter 4 can be helpful here in determining the topology.

Chapter 6 covers structural optimization which is always accompanied in shells by shape optimization. Hiroki Tamai and Daniel Gebreiter illustrate various methods, some still under development, that demonstrate, among other things, the importance of cooperation between architects and engineers during the design phase. Readers who wish to study the topic of form-finding and optimization in greater detail are also recommended to consult the book [22/1].

So as not to exceed limits, I have used only the grid shells designed by schlaich bergermann und partner (sbp) as executed examples, and have listed them in Chapter 8 together with essential information regarding geometry, structure and node formation. As publications exist for most of the projects, the relevant reference has been included for each in place of a detailed project description.

The book concludes with the chapter on Holistic Design, which is understood to be a complex interaction between geometry, topology and structural calculations in order to achieve specified optimization targets such as force-flow-oriented geometry and rod structure, weight minimization, homogeneous material utilization. etc.. This creates a delicate and effective structure with technical discipline and order that is of good quality and has excellent aesthetics; something which can only be achieved with close cooperation between architects and engineers at an early stage of design.
The idea of the book is to set down the knowledge relating to transparent shell structures that has been acquired at schlaich bergermann und partner, and to make it available to interested colleagues. The author's goal will have been achieved in full if, as a result, even just a few architects and structural engineers are encouraged to design aesthetic, efficient, and lightweight shell structures and thus to contribute to the "Baukultur" (building culture).

Hans Schober
Stuttgart, May 2015

Acknowledgements

During my employment at schlaich bergermann und partner, I have collaborated with many talented and motivated engineers without whose participation these projects would not have been possible. To list them all would mean naming a large proportion of the office team over the past 30 years, which is why I will confine myself to those with whom cooperation was particularly close.

I would like to thank:
Sven Plieninger, Stefan Justiz, Thomas Moschner, Michael Stein, Thomas Fackler, Michael Werwigk, Jochen Gugeler, Jörg Mühlberger, Matthias Nier, Kai Kürschner, Tilman Schober, Stefanie Schober, Daniel Gebreiter, Jan Knippers, Thorsten Helbig, Thomas Bulenda, Peter Schulze, Bernd Ruhnke, Hansmartin Fritz, Cornelia Striegan, Brian Hunt, Jochen Bettermann.

Where would the art of engineering be without bold, innovative and committed companies? They are something I particularly appreciate since working in New York City where it was hard to find glass construction companies with the necessary courage and craftsmanship for innovative designs. This meant that in many cases we had to rely on German subsidiaries in USA.

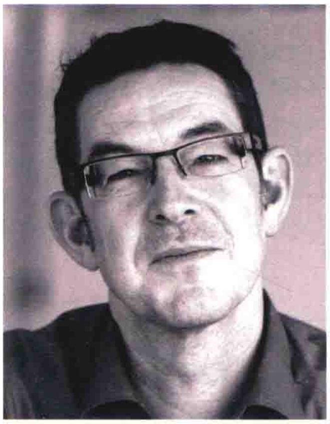
The following companies were instrumental in enabling us to implement our ideas and designs:
Helmut Fischer GmbH, Talheim, Germany
Mero TSK International GmbH und Co. KG, Würzburg, Germany
Josef Gartner GmbH, Gundelfingen, Germany
Permasteelisa Group, Vittorio Veneto, Italy
Seele GmbH, Gersthofen, Germany
Waagner-Biro, Stahlbau AG, Wien, Austria
Roschmann Konstruktionen aus Stahl und Glas GmbH, Gersthofen, Germany
Tripyramid Structures Inc., Westford, MA, USA
Müller Offenburg GmbH, Offenburg, Germany
Lacker GmbH und Co. KG, Waldachtal, Germany
W&W Glass, Nanuet, NY, USA

About the Author

Hans Schober, born in 1943, studied structural engineering at the University of Stuttgart and did his PhD to become Dr.-Ing. with Professor Jörg Schlaich at the Institute of Structural Design in 1984. From 1982, he worked as an engineer in the offices of schlaich bergermann und partner (sbp), becoming a partner himself in 1992 and heading the New York office from 2005 to 2009.

Since his return from New York, he has worked as a consultant for the Stuttgart office. During his long professional career, he has been involved in the design and construction of various footbridges, railway bridges and stations and has gathered ample experience in the design and construction of glass roofs, cable net façades and freeform structures.

With the collaboration of



Sven Plieninger, born in 1964 in Heilbronn, studied structural engineering at the University of Stuttgart and graduated as an engineer (Dipl.-Ing.) on completion of his studies. From 1991, he worked as an engineer at schlaich bergermann und partner (sbp) Stuttgart, becoming a partner himself in 2000 and has been a managing partner since 2002. He is involved mainly in projects in the field of education, sports and culture which are implemented worldwide, with the focus on China.

Stefan Justiz studied structural engineering at the Universities of Stuttgart and Calgary where he graduated as an engineer (Dipl.-Ing.) in 1995. Since then he has worked as an engineer at schlaich bergermann und partner (sbp) in Stuttgart where he is involved in the design and planning of structures for bridges, wide-span roofs and stadium canopies, with a special focus on glass and steel structures.

Daniel Gebreiter was born in 1982. He has master's degrees in architecture and sustainable building at the University of Nottingham (2005) and the Technical University of Berlin (2011).
In 2012, he gained the degree of M.Phil. in Digital Architectonics in postgraduate studies at the University of Bath. His thesis dealt with the computer-assisted design of freeform building envelopes.
Since then, Daniel Gebreiter has been a member of the dedicated Geometry and Structural Optimization Group at schlaich bergermann und partner (sbp) in Stuttgart. This group uses and develops digital tools for optimizing the structural analysis and geometry of large building structures and façades.
He previously worked at UN Studio in Amsterdam and Wilkinson Eyre Architects in London.

Hiroki Tamai studied architecture and structural engineering at Kyoto University, graduating with a Bachelor and Master of Science. He gained his PhD in architecture with Professor Mahjoub Elmineiri at the Illinois Institute of Technology in 2005. He worked at various architectural and engineering firms in the US before starting work as an engineer at the offices of schlaich bergermann und partner (sbp) in Stuttgart in 2008 where he is involved mainly in the structural optimization of glazed shells and wide-span stadium roofs and the development of form-finding programs.

Hans Schober

TRANSPARENT SHELLS
FORM TOPOLOGY STRUCTURE

Ernst & Sohn
A Wiley Brand

Hans Schober

TRANSPARENT SHELLS

FORM TOPOLOGY STRUCTURE

Ernst & Sohn
A Wiley Brand

Foreword

This book describes a specific, but beautiful, building design: the glass grid shell for large-span, double-curved glazed roofs with minimal structural weight and ingenious details.
Skilfully and diligently the description encompasses the whole range, from grid shells with flat quadrilateral meshes to freeform domes and the optimization of their shape, structure and construction, supported by many examples taken from the author's practical experience.
This book is aimed mainly at structural engineers. It introduces them to a new and attractive yet challenging field with which they can approach not only architects but also clients. It therefore opens up a whole range of opportunities to structural engineers, thanks not least to the many examples featured, including one of the first applications of this design principle which was applied in the roof of Munich's Olympic stadium in 1972. So I, who was fortunate to share an office with the author for many years and facilitate this development, can only welcome this multifaceted book with open arms and recommend it eagerly, in the certain hope that it will stimulate creative engineers to build other appealing structures using lightweight, elegant glass grid shells.

Jörg Schlaich
Berlin, May 2015

Preface

In the 1980s, technological development inspired the construction of single and double-curved glass buildings. The development of powerful computers and CAD programs, combined with CNC machines meant that geometrically complicated structures also became competitive. This led partly to a type of architecture that was unshackled, to "blob architecture" or organic, free-form architecture. Designing completely free forms requires special skills which very few designers possess, since only in the rarest cases are opulent and undisciplined "blobs" good architecture. Building design can only be called great architecture when an appealing appearance goes hand in hand with a clear functional design that is fit for its purpose. The building's visual appearance should be seen as an integrative part of the technical development.
During this period, the offices of schlaich bergermann und partner in Stuttgart developed grid shells: an innovative supporting structure that used prestressed cables to convert the supporting framework into a single-layer shell structure that is suitable for single and double-curved shapes.

This book is by no means exhaustive but in it I have set down my thoughts and experience regarding the development of these transparent shells; experience gathered since that time to the present in the offices of schlaich bergermann und partner sbp.
I owe a dept of gratitude to my teacher and longtime "boss" Jörg Schlaich for providing a creative, open environment in the office which made it possible for me to participate in interesting and innovative developments and to lead a fulfilling professional life.

The graphic design principles for grid shells, which are simple, clear and easy to understand and can readily be applied using the currently available modules of customary CAD programs, take up a significant proportion of the book.
There are now computer tools available that generate grids with the desired properties on unmeshed, completely freeform surfaces, thus producing homogeneous structures. Whilst this would be impossible without this software, I do believe that simple, understandable principles, whose basic mathematical and geometric concepts can be reconstructed and which therefore do not constitute a black box, still have their place. The mathematically based shapes are "justified" and disciplined, and mathematical relationships have their own inherent aesthetics. Rational design principles are timeless.
That which is understandable is usually perceived as good or right – this applies to both the geometry and the distribution of forces. With reference to the famous statement about good theory, Jörg Schlaich said it in a nutshell: "There is nothing more practical than a transparent theory."

In Chapter 5, I confine myself to brief notes on the use of complex programs for generating (geometric) grids on free forms. The simple graphic design principles of Chapter 4 can be helpful here in determining the topology.

Chapter 6 covers structural optimization which is always accompanied in shells by shape optimization. Hiroki Tamai and Daniel Gebreiter illustrate various methods, some still under development, that demonstrate, among other things, the importance of cooperation between architects and engineers during the design phase. Readers who wish to study the topic of form-finding and optimization in greater detail are also recommended to consult the book [22/1].

So as not to exceed limits, I have used only the grid shells designed by schlaich bergermann und partner (sbp) as executed examples, and have listed them in Chapter 8 together with essential information regarding geometry, structure and node formation. As publications exist for most of the projects, the relevant reference has been included for each in place of a detailed project description.

The book concludes with the chapter on Holistic Design, which is understood to be a complex interaction between geometry, topology and structural calculations in order to achieve specified optimization targets such as force-flow-oriented geometry and rod structure, weight minimization, homogeneous material utilization. etc.. This creates a delicate and effective structure with technical discipline and order that is of good quality and has excellent aesthetics; something which can only be achieved with close cooperation between architects and engineers at an early stage of design.
The idea of the book is to set down the knowledge relating to transparent shell structures that has been acquired at schlaich bergermann und partner, and to make it available to interested colleagues. The author's goal will have been achieved in full if, as a result, even just a few architects and structural engineers are encouraged to design aesthetic, efficient, and lightweight shell structures and thus to contribute to the "Baukultur" (building culture).

Hans Schober
Stuttgart, May 2015