

SECOND EDITION

# STRUCTURE AS ARCHITECTURE

A SOURCE BOOK FOR ARCHITECTS AND STRUCTURAL ENGINEERS

ANDREW CHARLESON



# Structure as Architecture

*Structure as Architecture* presents a comprehensive analysis of the indispensable role of structure in architecture. An exploration, as well as a celebration, of structure, the book draws on a series of design studies and case study examples to illustrate how structure can be employed to realize a wide range of concepts in contemporary architecture. By examining design principles that relate to both architecture and structural engineering, Andrew Charleson provides new insights into the relationship between both the technical and aesthetic aspects of architecture.

Now in its second edition, the text has been extensively revised and updated throughout. Features include:

- a brand new chapter on hidden structure, adding to the material on exposed structures
- two new chapters on using structure to realize common architectural concepts through a combination of precedents and creative design
- over fifty new case studies from across the globe
- easy-to-understand diagrams and a highly visual design to aid understanding and accessibility

More than two hundred case studies of contemporary buildings from countries such as the UK, the US, France, Germany, Spain, Hong Kong, Australia and Japan illustrate how a thorough integration of structure adds layers of richness and enhances the realization of architectural design concepts.

**Andrew Charleson** has visited, photographed and analysed almost all of the case-study buildings included in this book. He is an Associate Professor at the School of Architecture, Victoria University of Wellington, New Zealand. Bringing over forty years' structural engineering experience to the topic, he has also written *Seismic Design for Architects: Outwitting the Quake* and published many papers relating both to the subject of this book and to his other main areas of research interest – earthquake engineering and architecture.

*'Structure as Architecture* cuts to the heart of the architectural and engineering relationship. This book explores how form and function blend, where structural and architectural concepts interweave and support each other for a technically and aesthetically enhanced work. Andrew Charleson demonstrates his holistic approach to architecture and engineering through stunning case studies where designers seamlessly and elegantly blend structural engineering with the architect's design intent. As a structural engineer and architect, I truly believe this book is a must-read!

*Holger S. Schulze Ehring, Structural Designer, New York City*

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# Contents

|   |             |
|---|-------------|
| <b>List of figures</b>  | <b>viii</b> |
| <b>Preface</b>  | <b>xx</b>   |
| <b>Acknowledgements</b>   | <b>xxi</b>  |
| <b>Chapter 1. Introduction</b>  | <b>1</b>    |
| The potential for structure to enrich architecture                        | 1           |
| Experiencing structure: reading and listening                             | 2           |
| Structure and its degree of exposure                                      | 3           |
| Book outline  | 4           |
| <b>Chapter 2. Two building studies</b>                                    | <b>6</b>    |
| National Stadium, Beijing   | 6           |
| Baumschulenweg Crematorium  | 10          |
| Summary   | 13          |
| <b>Chapter 3. Relationships between architectural and structural form</b> | <b>14</b>   |
| Introduction  | 14          |
| Synthesis of architectural and structural form                            | 18          |
| Contrasting forms   | 32          |
| Summary   | 40          |
| <b>Chapter 4. Building exterior</b>                                       | <b>41</b>   |
| Introduction  | 41          |
| Aesthetic qualities   | 42          |
| Connecting the exterior to the interior                                   | 55          |
| Entry   | 56          |
| Expressive roles  | 58          |
| Summary   | 62          |

|  |            |
|--|------------|
| <b>Chapter 5. Building function</b>            | <b>63</b>  |
| Introduction                                   | 63         |
| Maximizing functional flexibility              | 64         |
| Subdividing space                              | 69         |
| Articulating circulation                       | 76         |
| Disrupting function                            | 78         |
| Summary  | 82         |
| <b>Chapter 6. Interior structure</b>           | <b>84</b>  |
| Introduction                                   | 84         |
| Surface structure                              | 85         |
| Spatial structure                              | 91         |
| Expressive structure                           | 99         |
| Summary  | 104        |
| <b>Chapter 7. Structural detailing</b>         | <b>106</b> |
| Introduction                                   | 106        |
| Expressive and responsive detailing            | 108        |
| Summary  | 124        |
| <b>Chapter 8. Structure and light</b>          | <b>125</b> |
| Introduction                                   | 125        |
| Source of light                                | 126        |
| Maximizing light                               | 132        |
| Modifier of light                              | 139        |
| Modified by light                              | 142        |
| Summary  | 144        |
| <b>Chapter 9. Representation and symbolism</b> | <b>145</b> |
| Introduction                                   | 145        |
| Representation                                 | 145        |
| Symbolism                                      | 155        |
| Summary  | 160        |

|   |            |
|---|------------|
| <b>Chapter 10. Hidden structure</b>                                       | <b>161</b> |
| Introduction  | 161        |
| Hidden structural systems and members                                     | 162        |
| Degrees of hiddenness   | 163        |
| Techniques for hiding structure   | 165        |
| Motivations for hiding structure  | 170        |
| Summary   | 174        |
| <b>Chapter 11. Expressing architectural concepts</b>                      | <b>175</b> |
| Introduction  | 175        |
| Order–chaos   | 176        |
| Stability–instability   | 181        |
| Static–dynamic  | 186        |
| Grounded–floating   | 192        |
| Summary   | 200        |
| <b>Chapter 12. Facilitating architectural qualities</b>                   | <b>202</b> |
| Introduction  | 202        |
| Simplicity–complexity   | 202        |
| Open–closed   | 206        |
| Lightweight–heavy   | 209        |
| Soft–hard   | 218        |
| Elegant–rough   | 222        |
| Summary   | 227        |
| <b>Chapter 13. Conclusions</b>  | <b>228</b> |
| Introduction  | 228        |
| Transformative power of structure   | 228        |
| Structural diversity  | 229        |
| Implications for the architectural and structural engineering professions | 229        |
| <b>Index</b>  | <b>231</b> |



# Figures

|      |   |    |
|------|---|----|
| 2.1  | National Stadium, Beijing, China, Herzog & De Meuron, 2008: an elevation of the stadium .....   | 6  |
| 2.2  | The perimeter steel structure wraps around the inner concrete bowl, Arup .....  | 7  |
| 2.3  | A physical model of the perimeter steel and roof gravity-resisting portal frame structure .....   | 7  |
| 2.4  | The bottom chords of the portal girders can be seen from the seating bowl .....   | 8  |
| 2.5  | A view of a V-shaped truss-column near its base .....   | 8  |
| 2.6  | Horizontal and diagonal members of portal girders are visible beyond the upper curved structure .....   | 8  |
| 2.7  | Columns supporting the concrete bowl are also inclined .....  | 9  |
| 2.8  | A flight of stairs with a visible soffit fully integrated with an inclined perimeter member .....   | 9  |
| 2.9  | Baumschulenweg Crematorium, Berlin, Axel Schultes Architects, 1999: front elevation .....   | 10 |
| 2.10 | Simplified ground-floor plan .....  | 11 |
| 2.11 | Condolence hall columns .....   | 12 |
| 2.12 | Annuli of light as column 'capitals' .....  | 12 |
| 2.13 | Light-slot between the side wall and the roof slab ...  | 13 |
| 2.14 | Texture and niches of the condolence hall side walls .....  | 13 |
| 3.1  | Library Square, Vancouver, Canada, Moshe Safdie and Associates Inc., 1995 .....   | 15 |
| 3.2  | Mont-Cenis Academy, Herne, Germany, Jourda & Perraudin, 1999: a glazed box with entry canopy .....  | 15 |
| 3.3  | Post and beam gravity structure .....   | 15 |
| 3.4  | Vertical trusses support the wall .....   | 16 |
| 3.5  | Exchange House, London, Skidmore, Owings & Merrill, 1993: arches enable the building to span the site .....                                     | 16 |
| 3.6  | A transverse exterior cross-braced frame .....  | 16 |
| 3.7  | Interior of a concrete shell structure .....  | 18 |
| 3.8  | Bus station, Cárceres, Spain, Justo García Rubio Arquitecto, 2003 .....   | 18 |
| 3.9  | Palazzetto dello Sport, Rome, Italy, Pier Luigi Nervi with A.Vitellozzi, 1957: inclined struts support the shell roof .....                     | 19 |
| 3.10 | Interior ribbed surface of the shell .....  | 19 |
| 3.11 | Eden Project, Cornwall, UK, Nicholas Grimshaw & Partners, 2001: a cluster of interlinked biomes .....   | 19 |
| 3.12 | Biome interior structure consisting of outer primary hexagons and an inner layer of braced rods .....   | 20 |
| 3.13 | Stellingen Ice Skating Rink and Velodrome, Hamburg, Germany, Silcher, Werner + Partners, 1996: overall form .....                               | 20 |
| 3.14 | Contrasting architectural qualities of fabric surface and interior structural elements .....  | 20 |
| 3.15 | Portuguese Pavilion, Lisbon, Portugal, Alvaro Siza, 1998 .....  | 21 |
| 3.16 | Dulles International Airport, Washington, D.C., USA, Saarinen (Eero) and Associates, 1962 .....   | 21 |
| 3.17 | Hall 26, Trade Fair, Hanover, Germany, Herzog + Partner, 1996: three catenaries span between masts .....  | 22 |
| 3.18 | A mast withstands opposing catenary tensions at its top and at mid-height .....   | 22 |
| 3.19 | National Art Centre, Tokyo, Japan, Kisho Kurokawa and Associates, 2006: vertical but curved ribs support and define the undulating façade ..... | 23 |
| 3.20 | The lower of the two cones and nearby ribs .....  | 23 |
| 3.21 | The Reichstag cupola, Berlin, Germany, Foster and Partners, 1999: radial ribs and circumferential tubes .....                                   | 23 |

|      |  |    |  |    |
|------|--|----|--|----|
| 3.22 | The interior of the cupola .....   | 23 | Calini, Castellazi, Fatigati & Pintonella, 1950:<br>curved roof beams over the main concourse .....  | 33 |
| 3.23 | Tobias Grau headquarters, Rellingen, Germany,<br>BRT Architekten, 1998: glue-laminated wooden<br>ribs enclose the ground-floor interior concrete<br>structure..... | 24 | 3.45 Unexpected interior arches in the TGV station.....  | 33 |
| 3.24 | Curved wooden ribs behind glass louvres .....  | 24 | 3.46 Santa Caterina Market, Barcelona, Spain, EMBT,<br>2005: tiled vaults over the main entrance.....  | 34 |
| 3.25 | Paul Klee Museum, Bern, Switzerland, Renzo<br>Piano Building Workshop, 2005: arches form<br>three different-sized 'hills' .....                                    | 25 | 3.47 Tangled tubular columns support trusses for the<br>tubular arches that form the vaults .....  | 34 |
| 3.26 | The arches also have a strong presence within<br>the interior.....   | 25 | 3.48 The length-wise trusses and the three<br>penetrating arch trusses that support them.....  | 35 |
| 3.27 | The Great Glasshouse, Carmarthenshire, Wales,<br>Foster and Partners, 1998.....  | 26 | 3.49 Novartis Building, Basel, Switzerland, Gehry<br>Partners, 2009: highly irregular architectural form ....  | 35 |
| 3.28 | Pequot Museum, Mashantucket, USA, Polshek<br>Partnership Architects, 2000: exterior view of<br>the curved and sloping glazed walls of main<br>public space .....   | 26 | 3.50 Less rational structure supporting the floors<br>around the internal atrium.....  | 35 |
| 3.29 | The horizontal arch supports the curved and<br>sloping wall .....  | 26 | 3.51 LASALLE College of the Arts, Singapore, RSP<br>Architects, 2007.....  | 36 |
| 3.30 | United Airlines Terminal, Chicago, USA, Murphy/<br>Jahn, 1987. Folded plates span the main entry<br>foyer.....   | 27 | 3.52 Stuttgart Airport terminal, Germany, Gerkan,<br>Marg + Partners, 1991 .....   | 36 |
| 3.31 | Riverside Museum, Glasgow, UK, Zaha Hadid, 2011 ...  | 27 | 3.53 Regional Government Centre, Marseille, France,<br>Alsop & Störmer, 1994: a combination of forms.....  | 37 |
| 3.32 | Gymnasium, Hong Kong, China: view from<br>above showing the folded plate construction .....  | 28 | 3.54 The X-columns in the atrium.....  | 37 |
| 3.33 | Interior of the gymnasium.....   | 28 | 3.55 Westminster College, London, UK, Schmidt<br>Hammer Lassen Architects, 2011: vertical and<br>raking columns form triangulated frames that<br>modulate the entry foyer .....      | 37 |
| 3.34 | Fuji TV building, Tokyo, Japan, Kenzo Tange, 1996.....   | 29 | 3.56 The front façade cantilevers while the facing<br>façade on the left steps back up its height .....  | 38 |
| 3.35 | San Cataldo Cemetery columbarium, Modena,<br>Italy, Aldo Rossi, 1984.....  | 30 | 3.57 A sloping column resists vertical load by a<br>combination of compression in the raking<br>members and either tension or compression in<br>the horizontal floor structure ..... | 38 |
| 3.36 | Princess of Wales Conservatory, London,<br>Gordon Wilson, 1986.....  | 30 | 3.58 Sendai Mediatheque, Sendai, Japan, Toyo Ito<br>& Associates, 2000: exterior view with some<br>structure visible behind the predominantly<br>glazed skin .....                   | 38 |
| 3.37 | Faculty of Journalism, Pamplona, Spain, Vicens<br>and Ramos, 1996: walls visually dominate the<br>exterior .....   | 30 | 3.59 The structure in the main library area, due to the<br>size and varying inclination of struts, appears to<br>sway.....   | 39 |
| 3.38 | An interior architecture of walls .....  | 31 | 3.60 The Great Court, British Museum, London,<br>Foster and Partners, 2000.....  | 39 |
| 3.39 | Zollverein School of Management and Design,<br>Essen, Germany, SANAA, 2007 .....   | 31 | 4.1 Hong Kong and Shanghai Bank, Hong Kong,<br>China, Foster Associates, 1986.....   | 41 |
| 3.40 | Prada Boutique Aoyama, Tokyo, Japan, Herzog<br>& De Meuron, 2003: the main entry and lower<br>floors of the six storeys above ground level.....                    | 32 | 4.2 Kursaal Auditorium and Conference Centre, San<br>Sebastian, Spain, Rafael Moneo, 1999 .....  | 43 |
| 3.41 | The structural diagrid wall is most clearly visible<br>from within the building .....  | 32 | 4.3 Yerba Buena Lofts, San Francisco, USA, Stanley<br>Saitowitz Office/Natoma Architects, 2002 .....   | 43 |
| 3.42 | Exchange House, London, Skidmore, Owings &<br>Merrill, 1993.....   | 32 | 4.4 RAC Control Centre, Bristol, UK, Nicholas<br>Grimshaw & Partners, 1995.....  | 44 |
| 3.43 | TGV station, Lille, France, SNCF/Jean-Marie<br>Duthilleul, 1994 .....  | 33 |  |    |
| 3.44 | Railway station, Rome, Montuori, Vitellozzi,   |    |  |    |

- 4.5 New Court, London, UK, OMA, 2011: along the street frontage, pairs of columns with occasional braces form a colonnade ..... 44
- 4.6 Expressed structure modulates the façade with randomly placed braces further enlivening it ..... 45
- 4.7 Velasca Tower, Milan, Italy, BBPR, 1958 ..... 45
- 4.8 Notre Dame Cathedral, Paris, 1260 ..... 46
- 4.9 Dulles International Airport, Washington, D.C., USA, Saarinen (Eero) and Associates, 1962 ..... 46
- 4.10 Student Canteen, Karlsruhe, Germany, J. Mayer Architects, 2007 ..... 47
- 4.11 Mönchengladbach Museum, Germany, Hans Hollein, 1982 ..... 47
- 4.12 Mound Stand, Lord's, London, Michael Hopkins & Partners, 1987 ..... 48
- 4.13 Canopy structure, World Exhibition Centre, Hanover, Germany, Herzog + Partner, 1999 ..... 48
- 4.14 Mikimoto Ginza 2 building, Tokyo, Japan, Toyo Ito & Associates, 2005: the surfaces of the planar perimeter walls are smooth, and the only hint of their depth is where openings are viewed obliquely ..... 49
- 4.15 The interior visual qualities of structure (lined with plasterboard) are similar to those of the exterior ..... 49
- 4.16 Exhibition Centre, Melbourne, Australia, Denton Corker Marshall, 1996: verandah posts visually soften the façade ..... 49
- 4.17 A view along the verandah ..... 50
- 4.18 Luxembourg Philharmonic Hall, Luxembourg, Christian de Portzamparc, 2005 ..... 50
- 4.19 Library Square, Vancouver, Canada, Moshe Safdie and Associates Inc., 1995 ..... 50
- 4.20 Jacob and Wilhelm Grimm Centre, Central library of Humboldt University, Berlin, Max Dudler, 2009 ..... 51
- 4.21 O-14 Tower, Dubai, Reiser + Umemoto, 2011 ..... 51
- 4.22 Broadgate Tower, London, UK, SOM, 2008: due to railway tracks running under the right-hand side of the tower, inclined struts transfer forces across to piers underneath the ground plane to the right ..... 52
- 4.23 The inclined structural canopy slices through the space between office blocks ..... 52
- 4.24 A simplified section to explain the transfer structure for vertical loads ..... 52
- 4.25 Cathedral of Notre Dame de la Treille, Lille, France, Pierre-Louis Slide Carlier Architecte, 1997: steel filigree structure supports the nave wall ..... 53
- 4.26 Horizontal steel structure spans between columns of a pre-stressed stone arch ..... 53
- 4.27 Cannon Bridge House, London, UK, Foggo Associates, 2012: the façade-truss structure spans the width of the building and is supported by cantilevered trusses at each end ..... 54
- 4.28 The cantilever truss diagonals comprise multiple members to reduce their size ..... 54
- 4.29 Law Courts, Bordeaux, France, Richard Rogers Partnership, 1998. .... 54
- 4.30 Cité des Sciences et de l'Industrie, Paris, Adrien Fainsilber, 1986 ..... 55
- 4.31 Stansted Airport terminal, Essex, UK, Foster Associates, 1991 ..... 55
- 4.32 Mont-Cenis Academy, Herne, Germany, Jourda & Perraudin, 1999 ..... 56
- 4.33 Public University of Navarra, Pamplona, Spain, Sáenz de Oiza Arquitectos, 1993 ..... 56
- 4.34 Millennium Stadium, Cardiff, Wales, The Lobb Partnership (now HOK Sports), 2000 ..... 57
- 4.35 Terminal 2F, Charles de Gaulle Airport, Paris, Aéroports de Paris, 1999: semi-circular columns signal entry ..... 57
- 4.36 A 'split column' viewed from inside ..... 57
- 4.37 National Museum of Emerging Science and Innovation, Tokyo, Japan, AMS Architects, 2001 ..... 58
- 4.38 Cité de la Musique, Paris, Christian de Portzamparc, 1995 ..... 58
- 4.39 S. Giorgio Maggiore, Venice, Italy, Palladio, 1610 ..... 59
- 4.40 Fitzwilliam College Chapel, Cambridge, UK, Richard MacCormac, 1991 ..... 59
- 4.41 Business School, Öhringen, Germany, Gunter Behnisch & Partner, 1993: the main entrance of the haphazardly orientated buttresses ..... 59
- 4.42 A horizontal plate passes through the buttress without making contact ..... 60
- 4.43 Peckham Library, London, UK, Alsop & Störmer, 2000: a row of casually placed and orientated columns support the elevated front façade of the lending library volume ..... 60
- 4.44 The columns exude a sense of informality ..... 61
- 4.45 Bracken House, London, Michael Hopkins and Partners, 1991: main façade ..... 61

|      |   |    |      |  |    |
|------|---|----|------|--|----|
| 4.46 | Metal columns, a cantilever bracket and a stainless-steel rod behind a stone pier .....   | 62 |      |  |    |
| 5.1  | Tugendhat House, Brno, Czech Republic, Mies van de Rohe, 1930 .....   | 64 | 5.24 | Library, Delft Technical University, The Netherlands, Mecanoo Architekten, 1997: a view of the cone above the turf roof.....         | 73 |
| 5.2  | Oxford Ice Rink, UK, Nicholas Grimshaw & Partners, 1985.....  | 65 | 5.25 | The circulation desk beneath the cone is surrounded by steel struts .....  | 74 |
| 5.3  | Hampden Gurney Church of England Primary School, London, UK, Building Design Partnership, 2002: the assembly hall .....   | 66 | 5.26 | Law Courts, Bordeaux, France, Richard Rogers Partnership, 1998 .....   | 74 |
| 5.4  | Inclined tension rods connect into the arched truss which also supports the two high points of a tension-membrane roof canopy .....   | 66 | 5.27 | Art Museum, Bregenz, Austria, Atelier Peter Zumthor, 1997: the building with the main entrance to the left.....                      | 74 |
| 5.5  | Bridge Academy, London, UK, Building Design Partnership, 2007: from an inclined roof-level horseshoe ring beam, a steeply sloping ETFE wall meets the Learning Resource Centre roof ..... | 66 | 5.28 | Simplified ground-floor plan .....   | 75 |
| 5.6  | A view through the sloping atrium.....  | 66 | 5.29 | Centraal Beheer Office Building, Apeldoorn, The Netherlands, Herman Hertzberger with Lucas & Niemeijer Architects, 1972 .....        | 75 |
| 5.7  | The column-free ground-floor gathering space .....  | 67 | 5.30 | Colegio Teresiano, Barcelona, Spain, Antoni Gaudí, 1889.....   | 76 |
| 5.8  | <i>Financial Times</i> printing works, London, Nicholas Grimshaw & Partners, 1988 .....   | 67 | 5.31 | San Cataldo Cemetery, Modena, Italy, Aldo Rossi, 1984 .....  | 77 |
| 5.9  | Toskana Thermal Pools, Bad Sulza, Germany, Ollertz & Ollertz, 1999: wooden shell structures .....   | 68 | 5.32 | Canary Wharf Underground Station, London, Foster and Partners, 1999 .....  | 77 |
| 5.10 | Open structure-free space under the shell roofs .....   | 68 | 5.33 | Terminal 3, Hamburg Airport, Germany, vonGerkan, Marg + Partners, 1991 .....   | 78 |
| 5.11 | Timber Showroom, Hergatz, Germany, Baumschlagler-Eberle, 1995.....  | 68 | 5.34 | Castelvecchio Museum, Verona, Italy, Carlo Scarpa, 1964 .....  | 78 |
| 5.12 | Sainsbury Centre for Visual Arts, Norwich, UK, Foster Associates, 1977 .....  | 69 | 5.35 | Research Centre, Seibersdorf, Austria, Coop Himmelb(l)au, 1995: the office block and its irregular columns .....                     | 79 |
| 5.13 | Exhibition Hall 3, Frankfurt, Germany, Nicholas Grimshaw & Partners, 2001 .....   | 69 | 5.36 | A column dominates the 'thinking room' .....   | 79 |
| 5.14 | Museum of Roman Art, Merida, Spain, Rafael Moneo, 1985: a view along the nave .....   | 69 | 5.37 | Convent of La Tourette, Evieux, France, Le Corbusier, 1959: the western façade and three levels of irregularly spaced mullions ..... | 80 |
| 5.15 | Floor slabs divide the space vertically.....  | 70 | 5.38 | Two columns on the right are set in from the exterior wall and intrude upon a teaching space .....                                   | 80 |
| 5.16 | Thermal Baths, Vals, Switzerland, Atelier Peter Zumthor, 1996: simplified ground-floor plan .....   | 70 | 5.39 | Pizza Express restaurant façade, 125 Alban Gate, London, Bere Associates, 1996.....  | 80 |
| 5.17 | Main interior pool, partially surrounded by walls.....  | 71 | 5.40 | 125 Alban Gate, London, Terry Farrell, 1992.....   | 81 |
| 5.18 | Némausus Apartments, Nîmes, France, Jean Nouvel et Associés, 1988.....  | 71 | 5.41 | California College of the Arts, San Francisco, USA, Tanner Leddy Mantum Stacy, 1999.....   | 81 |
| 5.19 | Contemporary Art Wing, Hamburg, Germany, O. M. Ungers, 1996: building exterior .....  | 71 | 5.42 | Staatsgalerie, Stuttgart, Germany, Stirling and Wilford, 1984.....   | 82 |
| 5.20 | Simplified ground-floor plan .....  | 72 | 5.43 | Scottish Exhibition Centre, Glasgow, Scotland, Parr Partnership, 1985.....   | 82 |
| 5.21 | Public University of Navarra, Pamplona, Spain, Sáenz de Oiza Arquitectos, 1993 .....  | 72 | 6.1  | Wöhlen High School, Switzerland, Santiago Calatrava, 1988: attractive structural framing pattern of the entrance foyer roof .....    | 85 |
| 5.22 | Terminal 4, JFK Airport, New York, USA, Skidmore Owings & Merrill, 2001: structure occupies the entry zone.....   | 73 |      |  |    |
| 5.23 | V-struts separate ticketing areas to the left from  |    |      | a circulation area and retail outlets on the floor beneath .....   | 73 |

|   |    |   |     |
|---|----|---|-----|
| 6.2 Refined wooden struts connect to the steel rod tension-ring and the rafters with deepened ends.....   | 85 | Spain, Richard Meier Architects, 1995: exterior glazed wall to the ramp hall with the ramp structure behind.....  | 95  |
| 6.3 Saint Benedict Chapel, Sumvitg, Switzerland, Peter Zumthor, 1989: chapel exterior.....  | 86 | 6.25 Ramp colonnade to the right and the innermost structural layer on the left.....  | 96  |
| 6.4 Chapel interior, facing towards the altar.....  | 86 | 6.26 Stadttor Building, Düsseldorf, Germany, Petzinka Pink und Partner, 1998: an interior braced tower is visible through the glazing.....  | 96  |
| 6.5 Ribbed roof structure.....  | 87 | 6.27 A view up through a tower.....   | 97  |
| 6.6 Bodegas Protos, Valladolid, Spain, Rogers Stirk Harbour + Partners, 2008.....   | 87 | 6.28 GC Prostho Museum Research Centre, Aichi, Japan, Kengo Kuma & Associates, 2010.....  | 97  |
| 6.7 FDA Laboratory, Irvine, California, USA, Zimmer Gunsul Frasca Partnership + HDR, 2003.....  | 87 | 6.29 Regent's Park Pavilion, London, UK, Carmody Groarke, 2009: the pavilion consists of 258 columns and a very lightweight penetrated roof.....                                      | 97  |
| 6.8 Güell Colony Crypt, Barcelona, Spain, Antoni Gaudí, 1917.....   | 88 | 6.30 Three seats amid the forest of slender columns.....  | 98  |
| 6.9 Building Industry School, Hamm, Germany, Heger Heger Schlieff, 1996.....  | 88 | 6.31 Fitzwilliam College Chapel, Cambridge, UK, Richard MacCormac, 1991: concrete frames demarcate a central area of the chapel interior.....   | 98  |
| 6.10 Saint Massimiliano Kolbe Church, Varese, Italy, Justus Dahinden, 1994: interior surface.....   | 88 | 6.32 The wooden roof is propped off an outer frame.....   | 98  |
| 6.11 A typical joint between ribs.....  | 89 | 6.33 Notre Dame du Raincy, Paris, France, Auguste Perret, 1923.....   | 99  |
| 6.12 Yohama International Passenger Terminal, Japan, Foreign Office Architects, 2002: folds of the roof folded plate structure are visible over the main entry.....               | 89 | 6.34 Museum of Gallo-Roman Civilization, Lyon, France, Bernard Zehrfuss, 1975: a central view of continuous and sloping columns.....  | 100 |
| 6.13 The folded plates as seen looking across the lobby...  | 90 | 6.35 Concrete frames extend over the galleries and corridor.....  | 100 |
| 6.14 Western Concourse, King's Cross Station, London, UK, John McAslan + Partners, 2012.....  | 90 | 6.36 Westminster Station, London, Michael Hopkins & Partners, 1999: tunnel lining exposed at a platform.....  | 100 |
| 6.15 Nicolas G. Hayek Centre, Tokyo, Japan, Shigeru Ban Architects, 2007: transparent columns and perimeter mullions support the curved and woven roof structure.....             | 90 | 6.37 Horizontal props between side walls.....   | 101 |
| 6.16 Different structural layouts affect how spaces are read.....   | 91 | 6.38 Props pass through central columns.....  | 101 |
| 6.17 Alternative structural layouts for resisting transverse lateral loads on a multi-storey building....   | 92 | 6.39 Arts Centre, Rotterdam, The Netherlands, Office for Metropolitan Architecture, 1992: columns in the auditorium lean towards the dais.....  | 101 |
| 6.18 Portland Building, University of Portsmouth, UK, Hampshire County Council Architects Department, 1996.....   | 93 | 6.40 Unusually configured roof-plane bracing.....   | 102 |
| 6.19 Lyon School of Architecture, Lyon, France, Jourda et Perraudin, 1988.....  | 93 | 6.41 An ambiguous relationship between a cantilevering slab and a tension-tie from the roof...  | 102 |
| 6.20 Kanagawa Institute of Technology (KAIT) workshop, Atsugi, Japan, Junya Ishigami and Associates, 2008: the interior structure forest is visible behind the glazed façade..... | 93 | 6.42 Channel 4 Headquarters, London, UK, Richard Rogers Partnership, 1995.....  | 103 |
| 6.21 Work benches and equipment are scattered around, never far from structure.....   | 94 | 6.43 Oxford University Museum, UK, Deane and Woodward, 1860.....  | 103 |
| 6.22 Hall, Wöhlen High School, Switzerland, Santiago Calatrava, 1988: a view towards the rear of the hall.  | 94 | 6.44 Peckham Library, London, UK, Alsop & Störmer, 2000: the exterior columns below the main library space move through it to support the roof and introduce an informal quality..... | 104 |
| 6.23 Looking across the hall.....   | 95 | 6.45 Sloping columns of three suspended pods also express informality.....  | 104 |
| 6.24 Museum of Contemporary Art, Barcelona,   |    |   |     |

|      |  |     |      |  |     |
|------|--|-----|------|--|-----|
| 7.1  | Several alternative structural member options for wooden post-and-beam construction .....  | 107 | 7.23 | Hedmark Museum, Hamar, Norway, Sverre Fehn, 2005 .....   | 116 |
| 7.2  | Several alternative structural member options for steel post-and-beam construction .....   | 107 | 7.24 | FABRICA (Benetton Communication Research Centre), Treviso, Italy, Tadao Ando & Associates, 2000 .....  | 116 |
| 7.3  | Several alternative structural member options for concrete post-and-beam construction .....  | 108 | 7.25 | Ferry terminal and office building, Hamburg, Germany, Alsop and Störmer, 1993: partially exposed precast-concrete A-frames .....                       | 117 |
| 7.4  | Grand Louvre, Paris, France, I. M. Pei, 1989: louvre pyramid.....  | 109 | 7.26 | Precast bracket and frame junction.....  | 117 |
| 7.5  | Coffered slab soffit.....  | 109 | 7.27 | Guggenheim Museum, Bilbao, Spain, Frank O. Gehry & Associates, 1997: view of the museum from the La Salve Bridge .....                                 | 118 |
| 7.6  | Triangular recesses within the central column relate to the pyramid above .....  | 109 | 7.28 | The tower structure and its exposed braced framework.....  | 118 |
| 7.7  | Suhr office building, Switzerland, Santiago Calatrava, 1985: the building is circular in plan, with an attached service core behind .....  | 110 | 7.29 | Fisher Center, Bard College, Annadale-on-Hudson, USA, Frank O. Gehry & Associates, 2002: side elevation with the main entry canopy to the right.....   | 118 |
| 7.8  | Perimeter blade-like strut .....   | 110 | 7.30 | Exposed construction of an exterior wall that curves towards the theatre roof .....  | 119 |
| 7.9  | Rounded precast-concrete stair stringer.....   | 110 | 7.31 | Carpentry School, Murau, Austria, E. Gislbrecht, 1992: end elevation.....  | 119 |
| 7.10 | Everlyn Grace Academy, London, UK, Zaha Hadid Architects, 2010 .....   | 111 | 7.32 | Web members connect to a truss bottom chord .....  | 119 |
| 7.11 | Tobius Grau KG office, Rellingen, Germany, BRT Architekten, 1998: structure of the office interior.....  | 111 | 7.33 | Face-loads only are transferred through the vertical plate-rod connection .....  | 120 |
| 7.12 | Fine diagonal bracing reads as 'stitching'.....  | 112 | 7.34 | Jussieu University, Paris, Edouart Albert, 1965.....   | 120 |
| 7.13 | Arts Centre, Rotterdam, The Netherlands, Office for Metropolitan Architecture, 1992: ungainly exterior beam.....   | 112 | 7.35 | Stadelhofen Railway Station, Zürich, Switzerland, Santiago Calatrava, 1990: escalator entrance structure.....  | 121 |
| 7.14 | Two of the three differently detailed columns.....   | 112 | 7.36 | Upper cantilever-to-torsion-beam connection, with smaller canopy cantilevers in the background.....  | 121 |
| 7.15 | Mossbourne Community Academy, London, UK, Rogers Stirk Harbour + Partners, 2004.....   | 113 | 7.37 | Stratford Regional Station, London, UK, Wilkinson Eyre, 1999 .....   | 122 |
| 7.16 | United Airlines Terminal, Chicago, USA, Murphy/Jahn, 1987: the main concourse .....  | 114 | 7.38 | Lyon School of Architecture, France, Jourda et Perraudin, 1988: a cast-steel shoe expresses the compression load-path.....                             | 122 |
| 7.17 | Innovative steel construction .....  | 114 | 7.39 | A beam-column connection that allows for a down-pipe to pass through where required.....   | 122 |
| 7.18 | Evelina Children's Hospital, London, Hopkins Architects, 2005: a steel lift-tower within the conservatory .....  | 114 | 7.40 | Palau Guëll, Barcelona, Spain, Antoni Gaudí, 1880 .....  | 123 |
| 7.19 | Towers express steel construction through the use of steel plates and stiffeners.....  | 115 | 7.41 | Glasgow School of Art, UK, Charles Rennie Mackintosh, 1899.....  | 123 |
| 7.20 | Bolts clamp tower sections together and a double-cantilevered beam supports a concrete bridge slab at one end and is held down at the other by a tensioned rod anchored in the foundations ..... | 115 | 7.42 | Post-Modern Art Museum, Stuttgart, Germany, James Stirling, Wilford & Associates, a984: classical detailing of a post-and-beam entrance structure..... | 123 |
| 7.21 | Hazel Wood School, Southampton, UK, Hampshire County Council Architects Department, 1990: the hall roof structure is typical of that for the whole school.....                                   | 115 |      |  |     |
| 7.22 | Short beams transfer loads from the lattice roof to a column .....   | 116 |      |  |     |

|      |  |     |      |  |     |
|------|--|-----|------|--|-----|
| 7.43 | Mushroom reinforced concrete columns in a gallery .....  | 124 | 8.21 | Schools of Geography and Engineering, Marne-la-Vallée, Paris, France, Chaix & Morel, 1996 .....                                    | 136 |
| 8.1  | Stellingen Ice Skating Rink and Velodrome, Hamburg, Germany, Silcher, Werner + Partners, 1996 .....  | 126 | 8.22 | Mexican Embassy, Berlin, Germany, González de León and Serrano, 2000 .....   | 136 |
| 8.2  | San Francisco International Airport, USA, Skidmore Owings & Merrill LLP, 2000: a side two-dimensional truss transforms into three dimensions over the central span of the terminal... .. | 127 | 8.23 | Broadfield House Glass Museum, West Midlands, UK, Design Antenna, 1994 .....   | 137 |
| 8.3  | Light passes through a three-dimensional truss .....   | 127 | 8.24 | Town Administrative Centre, Saint-Germain-en-Laye, Paris, France, Brunet and Saunier, 1995: glass columns support roof beams ..... | 137 |
| 8.4  | Dome Leisure Centre, Doncaster, UK, FaulknerBrowns Architects, 1989 .....  | 128 | 8.25 | A glass column base detail .....   | 137 |
| 8.5  | Kew Swimming and Recreation Centre, Melbourne, Australia, Daryl Jackson Architects, 1990 .....   | 128 | 8.26 | Apple Store, New York, USA, Bohlin Cywinski Jackson, 2002: the central glass staircase .....                                       | 138 |
| 8.6  | Sant Jordi Sports Hall, Barcelona, Spain, Arata Izosaki & Associates, 1990 .....   | 129 | 8.27 | Stair-treads connect to the glass wall .....   | 138 |
| 8.7  | Burrell Gallery, Glasgow, UK, Barry Gasson Architects, 1983 .....  | 129 | 8.28 | Yurakucho subway canopy, Tokyo International Forum, Tokyo, Japan, Rafael Vigñoly Architects, 1996 .....                            | 138 |
| 8.8  | Portuguese Pavilion, Lisbon, Portugal, Alvaro Siza, 1998 .....   | 130 | 8.29 | City of Arts and Sciences, Valencia, Spain, Santiago Calatrava, 1998: l'Umbracle with its garden shade-structure .....             | 139 |
| 8.9  | Railway station at Satolas Airport, Lyon, France, Santiago Calatrava, 1994: glazing centred over the main concourse .....  | 130 | 8.30 | Shade-structure arches and ribs .....  | 139 |
| 8.10 | A view across the concourse .....  | 131 | 8.31 | Seed House and Forestry Centre, Marche-en-Famenne, Belgium, Samyn et Associés, 1996: exterior view .....                           | 140 |
| 8.11 | Recessed lights in stub columns .....  | 131 | 8.32 | Shading increases at the splice positions of the transverse arches .....   | 140 |
| 8.12 | Stadelhofen Railway Station, Zürich, Switzerland, Santiago Calatrava, 1990 .....   | 131 | 8.33 | Mönchengladbach Museum, Germany, Hans Hollein, 1982 .....  | 141 |
| 8.13 | Trade Fair Glass Hall, Leipzig, Germany, Ian Ritchie Architects, 1996: exterior trusses support the vaulted grid-shell .....   | 132 | 8.34 | Business School, Öhringen, Germany, Günter Behnisch & Partner, 1993 .....  | 141 |
| 8.14 | Trusses and the grid-shell as seen from within the hall .....  | 133 | 8.35 | Library Square, Vancouver, Canada, Moshe Safdie and Associates Inc., 1995 .....  | 141 |
| 8.15 | Cité des Sciences et de l'Industrie, Paris, Adrien Fainsilber, 1986: Les Serres or conservatories on the main façade .....   | 133 | 8.36 | Mound Stand, Lord's, London, Michael Hopkins and Partners, 1987 .....  | 142 |
| 8.16 | A hierarchy of prestressed cable-beams resist face-loads on the glazed walls .....   | 133 | 8.37 | Timber Showroom, Hergatz, Germany, Baumschläger-Eberle, 1995 .....   | 142 |
| 8.17 | School at Waidhausenstraße, Vienna, Austria, Helmut Richter, 1995: composite steel walkway beams .....   | 134 | 8.38 | Mönchengladbach Museum, Germany, Hans Hollein, 1982 .....  | 143 |
| 8.18 | Triangular cantilever trusses support the mono-slope glazed roof .....   | 134 | 9.1  | Palais de Justice, Melun, France, Jourda & Perraudin Architectes, 1998 .....   | 146 |
| 8.19 | Carré d'Art, Nîmes, France, Sir Norman Foster and Partners, 1993: glass stair-treads and the supporting structure in the atrium .....  | 135 | 9.2  | Tod's Omotesando Building, Tokyo, Japan, Toyo Ito & Associates, 2004 .....   | 147 |
| 8.20 | Bevelled and set-back beams .....  | 135 | 9.3  | Oriente Station, Lisbon, Portugal, Santiago Calatrava, 1996: a lightweight platform canopy atop a heavy base .....                 | 147 |
|      |  |     | 9.4  | A view along the canopy structure .....  | 147 |
|      |  |     | 9.5  | Palm tree frond-like ribs connect to a primary arch .....  | 148 |

|       |   |     |  |  |  |
|-------|---|-----|--|--|--|
| 9.6   | Stansted Airport terminal, UK, Foster Associates, 1991.....   | 148 |  |  |  |
| 9.7   | Aluminium Centre, Houten, The Netherlands, Micha de Haas, 2002.....   | 148 |  |  |  |
| 9.8   | Outdoor Activities Centre, Portsmouth, UK, Hampshire County Architects, 1995.....   | 149 |  |  |  |
| 9.9   | Wöhlen High School entry canopy, Switzerland, Santiago Calatrava, 1988: ribs cantilever from the main arch.....   | 149 |  |  |  |
| 9.10  | Feet-like base-plates to the window mullions behind the canopy.....   | 149 |  |  |  |
| 9.11  | Glass Hall, Tokyo International Forum, Tokyo, Japan, Rafael Viñoly Architects, 1996: the full-height glazed wall facing the other sections of the Forum complex.....          | 150 |  |  |  |
| 9.12  | The roof structure as seen from the main concourse.....   | 150 |  |  |  |
| 9.13  | Closer to the roof, the tension rods become more visible.....   | 151 |  |  |  |
| 9.14  | The roof structure can be thought of simply as a tied arch (a) that is inverted with the arch then functioning as a catenary and the tie as a compression member (b).....     | 151 |  |  |  |
| 9.15  | Armenian School Library, Los Angeles, USA, StudioWorks Architects, 2003: the 'ark' is elevated above the school playground.....   | 152 |  |  |  |
| 9.16  | The main columns align with the keel and are flanked by stabilizing posts.....  | 152 |  |  |  |
| 9.17  | Atlantic Pavilion, Lisbon, Portugal, Skidmore Owings & Merrill plc, 1998: the sleek pavilion roof.....  | 152 |  |  |  |
| 9.18  | Wooden trussed-arches oversail the seating.....   | 153 |  |  |  |
| 9.19  | Youth Club, Möglingen, Stuttgart, Germany, Peter Hübner, 1996: building exterior.....   | 153 |  |  |  |
| 9.20  | A primary structural roof support displaying space-age detailing.....   | 153 |  |  |  |
| 9.21  | Wöhlen High School library roof, Switzerland, Santiago Calatrava, 1988.....   | 154 |  |  |  |
| 9.22  | Church of the Autostrada, Florence, Italy, Giovanni Michelucci, 1968: the church as seen from the motorway.....   | 154 |  |  |  |
| 9.23  | Dramatic interior structure with the main altar to the left facing the rows of seats.....   | 155 |  |  |  |
| 9.24  | Details of the concrete structure.....  | 155 |  |  |  |
| 9.25  | Jewish Museum, Berlin, Germany, Daniel Libeskind, 1998.....   | 156 |  |  |  |
| 9.26  | Felix Nussbaum Museum, Osnabrück, Germany, Daniel Libeskind, 1998: dysfunctional concrete beams in the Nussbaum Corridor.....   | 157 |  |  |  |
| 9.27  | Beams passing across the light-slot read as the bars of prison cells.....   | 157 |  |  |  |
| 9.28  | Imperial War Museum-North, Manchester, UK, Studio Daniel Libeskind, 2002.....   | 158 |  |  |  |
| 9.29  | Federation Square, Melbourne, Australia, Lab Architectural Studio and Bate Smart Partners, 2002: the tangled structure of the atrium roof.....                                | 158 |  |  |  |
| 9.30  | A perimeter walkway through the wall structure of the BMW Edge amphitheatre.....  | 159 |  |  |  |
| 9.31  | Industrial Park Office Building, Völkermarkt, Carinthia, Austria, Günther Domenig, 1996: the framed block supporting the cantilever with the lift and stair tower behind..... | 159 |  |  |  |
| 9.32  | Steel cantilever structure.....   | 159 |  |  |  |
| 10.1  | An elevational study of two exterior structural systems, a moment frame and a coupled shear wall.....   | 163 |  |  |  |
| 10.2  | China Central Television (CCTV) Headquarters, Beijing, OMA, 2009.....   | 163 |  |  |  |
| 10.3  | Okumura Memorial Museum, Nara, Japan, 2007. A base-isolation rubber bearing between red-painted base-plates is proudly displayed in the basement.....                         | 164 |  |  |  |
| 10.4  | Office building, Wellington, New Zealand.....   | 164 |  |  |  |
| 10.5  | N.W. Corner Building, Columbia University, New York, USA, Rafael Moneo, 2011.....   | 165 |  |  |  |
| 10.6  | HL23, New York, USA, Neil M. Denari Architects, 2009.....   | 165 |  |  |  |
| 10.7  | Examples of structural function being hidden (misrepresented) by structural detailing.....  | 166 |  |  |  |
| 10.8  | San Francisco Museum of Modern Art, San Francisco, USA, Mario Botta, 1995: the structural steel framework during construction.....  | 167 |  |  |  |
| 10.9  | A view of the building with its non-structural masonry cladding panels indicative of load-bearing masonry construction.....   | 167 |  |  |  |
| 10.10 | Serpentine Gallery Pavilion, London, UK, Frank O. Gehry, 2008.....  | 167 |  |  |  |
| 10.11 | De Young Museum, San Francisco, USA, Herzog & De Meuron, 2005.....  | 167 |  |  |  |
| 10.12 | The Lowry Centre, Salford, UK, Michael Wilford, 2000.....   | 168 |  |  |  |
| 10.13 | Kursaal Congress Centre and Auditorium, San Sebastian, Spain, Rafael Moneo, 1999.....   | 168 |  |  |  |
| 10.14 | Colegio Teresiano, Barcelona, Spain, Antoni   |     |  |  |  |



|       |  |     |  |       |  |
|-------|--|-----|--|-------|--|
|       | Gaudí, 1889: a spiral brick masonry column that is not immediately recognized as structure .....   | 169 |  |       |  |
| 10.15 | Slender single brick columns that appear too fragile to function as structure .....  | 169 |  | 11.7  | 1111 Lincoln Rd, Miami Beach, Florida, USA, Herzog & De Meuron, 2010 .....   |
| 10.16 | MUMUTH Music School and Theatre, Graz, Austria, UN Studio, 2008 .....  | 169 |  | 11.8  | Serpentine Summer Pavilion, London, Frank O. Gehry, 2008 .....   |
| 10.17 | Minnaert Building, University of Utrecht, The Netherlands, Neutelings Riedijk Architecten, 1997 .....  | 169 |  | 11.9  | Michael Lee-Chin Crystal, Royal Ontario Museum, Toronto, Canada, Daniel Libeskind, 2007: two contrasting architectures and structures .....  |
| 10.18 | Library, Delft Technical University, The Netherlands, Mecanoo Architecten, 1997 .....  | 170 |  | 11.10 | The chaotic quality of interior structure near the main façade .....   |
| 10.19 | London Aquatic Centre, London, UK, Zaha Hadid, 2011: the extensive and complex roof structure .....  | 171 |  | 11.11 | The additional structural actions or cross-sectional dimensions to achieve stable leaning and bent posts .....   |
| 10.20 | The sleek form is uncompromised by exposed structure .....   | 171 |  | 11.12 | Structural configurations expressing stability through to instability .....  |
| 10.21 | BMW Welt, Munich, Germany, Coop Himmelb(l)au, 2007: exterior form with the 'cloud' roof emanating from the vortex of the 'double cone' ..... | 171 |  | 11.13 | Horizontal forces acting on the roof diaphragm from the sloping columns, and the necessary stabilizing forces from the perimeter walls .....   |
| 10.22 | Large open spaces achieved by deep and complex roof structure hidden by ceiling panels .....   | 171 |  | 11.14 | Vancouver Law Courts, Vancouver, Canada, Arthur Erickson, 1980 .....   |
| 10.23 | Forum Building, Barcelona, Spain, Herzog & De Meuron, 2004 .....   | 172 |  | 11.15 | The Cathedral of Christ the Light, Oakland, CA, USA, C. Hartman, 2008 .....  |
| 10.24 | Guthrie Theater, Minneapolis, USA, Jean Nouvel, 2006 .....   | 172 |  | 11.16 | Jussieu University, Paris, France, Edouart Albert, 1965 .....  |
| 10.25 | Leutschenbach School, Zürich, Switzerland, Christian Kerez, 2008 .....   | 172 |  | 11.17 | Sharp Centre, Ontario College of Art & Design, Toronto, Canada, Alsop Architects, 2004 .....   |
| 10.26 | Office building, Wellington, New Zealand .....   | 173 |  | 11.18 | Médiathèque, Marseille, France, Alsop & Störmer, 1994 .....  |
| 10.27 | Office building, San Francisco, USA: slender structural steel columns .....  | 173 |  | 11.19 | The Beehive, Culver City, USA, Eric Owen Moss Architects, 2001 .....   |
| 10.28 | Removal of some cladding to a column reveals its true size .....   | 173 |  | 11.20 | Spittelau Viaducts Housing, Vienna, Austria, Zaha Hadid, 2005 .....  |
| 10.29 | Bechtler Museum of Modern Art, Charlotte, USA, Mario Botta, 2010 .....   | 174 |  | 11.21 | Photovoltaic pergola, Barcelona, Spain, Architectos Architects, 2004 .....   |
| 11.1  | Theoretical studies of how structural configuration can express order through to chaos ....  | 178 |  | 11.22 | Structural configuration varies from static to dynamic .....   |
| 11.2  | Eiffel Tower, Paris, France, G. Eiffel, 1889 .....   | 179 |  | 11.23 | Museum of Anthropology, Vancouver, Canada, Arthur Erickson, 1976 .....   |
| 11.3  | Piazza of St Peter's, Rome, Italy, Bernini, 1667 .....   | 179 |  | 11.24 | The West Building, Vancouver Convention Centre, Vancouver, Canada, LMN Architects, MCM Architects and DA Architects + Planners, 2009: external columns slope towards the inlet ..... |
| 11.4  | New Gallery, Berlin, Germany, Mies van der Rohe, 1968 .....  | 179 |  | 11.25 | Sloping columns intensify the experience of viewing from inside .....  |
| 11.5  | Melbourne Museum, Melbourne, Australia, Denton Corker Marshall, 2000 .....   | 180 |  | 11.26 | One New Change, London, UK, Jean Nouvel, 2010 .....  |
| 11.6  | Apartment and office building Schlachthausgasse, Vienna, Austria, Coop Himmelb(l)au, 2005 .....  | 180 |  | 11.27 | Bilbao Metro, Bilbao, Spain, Foster and Partners, 1996 .....   |

|       |   |     |       |  |     |
|-------|---|-----|-------|--|-----|
| 11.28 | Mexican Embassy, Berlin, González de León and Serrano, 2000 .....   | 190 |       |  |     |
| 11.29 | Barajas Airport, Madrid, Spain, Richard Rogers Partnership, 2006.....   | 190 | 11.51 | De Young Museum, San Francisco, USA, Herzog & De Meuron, 2005.....   | 199 |
| 11.30 | Philharmonie, Berlin, Germany, Hans Scharoun, 1963 .....  | 190 | 11.52 | Gatehouse canopy, Trumpf Factory, Stuttgart, Germany, Barkow Leibinger, 2010.....  | 200 |
| 11.31 | The Cooper Union, New York, USA, Morphosis, 2009.....   | 191 | 11.53 | Maggie's Centre, London, UK, Rogers Stirk Harbour & Partners, 2008: the roof cantilevers from set-back posts along the glazed first-floor walls..... | 200 |
| 11.32 | Choreography Centre, Aix-en-Provence, France, Rudy Ricciotti Architecte, 2004 .....                                       | 191 | 11.54 | The roof is supported by fine steel tubes that raise it above the beams.....   | 200 |
| 11.33 | Library addition, Leonardo Campus, Münster, Germany, Zauberschoën and Buehler and Buehler Architects, 2010 .....          | 191 | 11.55 | Notre Dame de la Duchère, Lyon, France, F. Cottin, 1972: posts supporting the roof are barely discernible .....                                      | 201 |
| 11.34 | Different degrees of grounding: structural (cantilever) walls, cantilever columns and columns of pin-jointed frames ..... | 193 | 11.56 | The exterior wall is structurally separated from the roof by glazing.....  | 201 |
| 11.35 | Options for reducing the sense of grounding of structural walls .....   | 193 | 12.1  | Villa Savoye, Paris, France, Le Corbusier, 1929: the front and side elevation.....   | 203 |
| 11.36 | Ordrupgaard Museum extension, Copenhagen, Denmark, Zaha Hadid, 2005 .....   | 194 | 12.2  | Plain exterior column and beam detailing .....   | 203 |
| 11.37 | Rolex Learning Centre, Lausanne, Switzerland, SANAA, 2009.....  | 194 | 12.3  | Millennium Seed Bank, Wakehurst Place, UK, Stanton Williams, 2000: barrel-vaulted roof forms.....  | 203 |
| 11.38 | Mellat Park Cineplex, Tehran, Iran, Fluid Motion Architects, 2008.....  | 194 | 12.4  | Detailing matches the simple structural forms .....  | 204 |
| 11.39 | Mellat Gallery, Tehran, Iran, Fluid Motion Architects, 2008.....  | 194 | 12.5  | Vancouver Convention Centre West, Vancouver, Canada, DA Architects + Planners, 2009 .....  | 204 |
| 11.40 | Church at Porta, Brissago, Switzerland, Raffaele Cavadini, 1997 .....   | 195 | 12.6  | Entrance canopy, Terminal 3, Heathrow Airport, London, UK, Foster and Partners, 2009 .....   | 204 |
| 11.41 | Splash Leisure Centre, Sheringham, UK, Alsop & Lyall, 1988.....   | 195 | 12.7  | Schlumberger extension building, Cambridge, UK, Michael Hopkins and Partners, 1992.....  | 205 |
| 11.42 | Terminal 3, Beijing Airport, Beijing, China, Foster and Partners, 2008.....   | 195 | 12.8  | <i>Financial Times</i> printing works, London, UK, Grimshaw & Partners, 1988.....  | 205 |
| 11.43 | Taisei Sapporo Building, Sapporo, Japan, Taisei Design Planners Architects and Engineers, 2006.....                       | 196 | 12.9  | Verbier Sports Centre, Switzerland, André Zufferey, 1984: complex stepping roof form .....   | 205 |
| 11.44 | Paddington Station addition, London, UK, 2011 .....   | 196 | 12.10 | Visually complex roof structure.....   | 205 |
| 11.45 | Unilever Building, Rotterdam, The Netherlands, JHK Architekten, 2005 .....  | 197 | 12.11 | Louvre Pyramid, Paris, France, I. M. Pei, 1989: visually complex structure within a simple form.....   | 206 |
| 11.46 | University of Alicante Museum, Alfredo Payá Benedito, 1999.....   | 197 | 12.12 | A strong internal core is required where perimeter structure is minimized to create openness between the interior and exterior.....                  | 206 |
| 11.47 | Vanke Centre, Shenzhen, China, Steven Holl Architects, 2009.....  | 197 | 12.13 | Extension to the Natural History Museum, London, UK, C. F. Moller Architects, 2009: the west-facing façade with the 'cocoon' behind.....             | 207 |
| 11.48 | Hoki Museum, Chiba, Japan, Yamanashi, Nakamoto, Suzuki and Yano, 2010: the steel tube, housing a gallery .....            | 198 | 12.14 | The 'cocoon' .....   | 207 |
| 11.49 | View from within the gallery .....  | 198 | 12.15 | Evelina Children's Hospital, London, UK, Hopkins Architects, 2005: the 100-metre-long atrium is effectively a light-filled conservatory.....         | 207 |
| 11.50 | Marina Bay Sands, Singapore, Safdie Architects,   |     |       |  |     |

|       |  |     |       |  |     |
|-------|--|-----|-------|--|-----|
| 12.16 | Floor plans become more and more closed as the number of walls increases.....  | 208 | 12.36 | Hong Kong and Shanghai Bank, Hong Kong, China, Foster Associates, 1986.....  | 216 |
| 12.17 | Museum of Roman Art, Merida, Spain, Rafael Moneo, 1985.....  | 208 | 12.37 | Centre for Understanding the Environment (CUE), Horniman Museum, London, UK, Architype, 1997: front façade with chimney-like columns .....   | 216 |
| 12.18 | Lyon School of Architecture, Lyon, France, Jourda et Perraudin, 1988: a wall encloses offices and an atrium within.....  | 208 | 12.38 | Interior column and beam .....   | 217 |
| 12.19 | The atrium surrounded by offices and the perimeter wall beyond .....   | 209 | 12.39 | Suntory Museum, Tokyo, Japan, Kengo Kuma & Associates, 2007.....   | 217 |
| 12.20 | FDA Laboratory, Irvine, CA, USA, Zimmer Gunsul Frasca Partnership + HDR, 2003 .....  | 209 | 12.40 | 21_21 Design Sight, Tokyo, Japan, Tadeo Ando & Associates, 2007.....   | 217 |
| 12.21 | Terminal 2F, Charles de Gaulle Airport, Paris, France, Aéroports de Paris, 1999: lightweight 'peninsula' roof .....  | 210 | 12.41 | Tama Art University Library, Hachioji City, Japan, Toyo Ito & Associates, 2007: two curved exterior walls express the surface of structure that takes on three-dimensional form inside ..... | 218 |
| 12.22 | Tension-spokes allow roof frames to wrap around the cantilevered floor slab.....   | 210 | 12.42 | Structure, curved in elevation and in plan .....   | 218 |
| 12.23 | National Library, Singapore, T.R. Hamzah and K. Yeang, 2004 .....  | 211 | 12.43 | Law Faculty extension, Limoges, France, Massimiliano Fuksas, 1997 .....  | 219 |
| 12.24 | Arab World Institute, Paris, France, Jean Nouvel, 1987: light vierendeel trusses support the front façade .....  | 211 | 12.44 | Santispark Health and Leisure Centre, St Gallen, Switzerland, Raush, Ladner, Clerici, 1986: the roof curves down from the ridge .....  | 219 |
| 12.25 | Ornate internal horizontal trusses by virtue of their detailing .....  | 211 | 12.45 | Roof structure with its deliberate sagging profile .....   | 219 |
| 12.26 | Centre Pompidou, Paris, France, Piano and Rogers, 1977.....  | 212 | 12.46 | Licorne football stadium, Amiens, France, Chaix & Morel et Associés, 1999.....   | 220 |
| 12.27 | United Airlines Terminal, Chicago, USA, Murphy/Jahn, 1987.....   | 212 | 12.47 | Barcelona Fair GranVia Venue, Barcelona, Spain, Toyo Ito, 2007 .....   | 220 |
| 12.28 | Learning Resource Centre, Thames Valley University, UK, Richard Rogers Partnership, 1996: both heavy and lightweight forms are visible from the exterior ..... | 212 | 12.48 | Faculty of Law Building, Cambridge, UK, Foster and Partners, 1996.....   | 220 |
| 12.29 | Curved beams arch over a computing area.....   | 213 | 12.49 | Museum of Anthropology, Vancouver, Canada, Arthur Erickson, 1976.....  | 221 |
| 12.30 | Portland Building, University of Portsmouth, UK, Hampshire County Council Architects Department, 1996.....   | 213 | 12.50 | Swimming pool, Barcelona, Spain, J. Antonio, 1996 .....  | 221 |
| 12.31 | Brookfield Place, Toronto, Canada, Santiago Calatrava, 1993.....   | 213 | 12.51 | Church at Porta, Brissago, Switzerland, Raffaele Cavadini, 1997 .....  | 222 |
| 12.32 | Wöhlen High School, Switzerland, Santiago Calatrava, 1988.....   | 214 | 12.52 | Felix Nussbaum Museum, Osnabrück, Germany, Daniel Libeskind, 1998 .....  | 222 |
| 12.33 | Stadelhofen Railway Station, Zürich, Switzerland, Santiago Calatrava, 1990: cambering the beams and the 'sloping columns' visually lighten the structure.....  | 214 | 12.53 | Bracken House, London, UK, Michael Hopkins and Partners, 1991: elegant truss members meet at a joint.....  | 223 |
| 12.34 | Pier detailing reduces visual mass.....  | 215 | 12.54 | Interior columns reflect the curved plan shape of the new insertion.....   | 223 |
| 12.35 | Moscone Center, San Francisco, USA, Hellmuth, Obata and Kassabaum, 1981 .....  | 215 | 12.55 | Queen's Building, Cambridge, UK, Michael Hopkins and Partners, 1995: main façade.....  | 223 |
|       |  |     | 12.56 | Refined roof truss detailing.....  | 224 |
|       |  |     | 12.57 | A post-tensioning node detail .....  | 224 |

|       |  |     |  |  |  |
|-------|--|-----|--|--|--|
| 12.58 | Sainte-Geneviève Library, Paris, France, Henri Labrouste, 1850 .....   | 224 |  |  |  |
| 12.59 | MUMUTH Music School and Theatre, Graz, Austria, UN Studio, 2008 .....  | 225 |  |  |  |
| 12.60 | Attic conversion, Vienna, Austria, Coop Himmelb(l)au, 1988: the attic roof oversails the existing building ..... | 225 |  |  |  |
| 12.61 | Irregularity of the form is reflected in the roughness of the detailing.....                                     | 225 |  |  |  |
| 12.62 | LASALLE College of the Arts, Singapore, RSP Architects, 2007 .....   | 226 |  |  |  |
| 12.63 | Güell Colony Crypt, Barcelona, Spain, Antoni Gaudí, 1917 .....   | 226 |  |  |  |
| 12.64 | Pedestrian footbridge, Stratford, London, UK, Buro Happold Services and Knight Architects, 2009.....             | 227 |  |  |  |

# Preface

The second edition of this book is based largely on the first, with a number of significant enhancements. Three new chapters have been introduced, of which two consider the topic of structure in architecture from a new perspective. The first edition concentrated upon an *analysis* of architectural structure. It analysed and illustrated the many architectural roles structure plays in both physical and conceptual ways. Its starting point was structure as manifest in existing architecture. Now, the additional two chapters focus on the same topic, but from the perspective of *design*. They begin from the basis of architects' design concepts and architectural qualities and show how structure positively reinforces the most common contemporary design concepts and facilitates desired spatial and other qualities.

This new emphasis on design, rather than analysis, brings a welcome balance to the book. The process of developing this material involved an interesting journey to identify and summarize current architectural concepts and qualities, and then illustrate them from existing works of architecture. One of the most rewarding aspects of this design-orientated emphasis was the design study undertaken by one of my postgraduate classes. Students designed spatial structure to

convey a wide range of design concepts. The most relevant outcomes are presented in Chapter 11.

As well as the introduction of this design-related content, the third new chapter shifts the focus upon *exposed* structure to structure that is *hidden*. This exploration not only acknowledges pragmatic aspects of structural hiddenness, but also aims to stimulate greater creativity in the concealment of structure.

This new edition has also provided an opportunity to update case-studies, and broaden their geographical catchment. Thirty per cent of the case-studies are new additions, many from countries previously unrepresented, most notably Japan.

In spite of all of these and other improvements, the central theme of the book remains unchanged: where structure contributes architecturally, other than in its primary load-bearing role, it contributes other layers of aesthetic and functional richness to designs. It reinforces architectural design concepts and intended architectural qualities, thereby increasing the interest in and enjoyment of buildings, raising the spirits of their occupants.

Andrew Charleson  
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Finally, thanks again to my wife Annette for her support and encouragement throughout this project.

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one

# Introduction

Structure is columnar, planar, or a combination of these which a designer can intentionally use to reinforce or realize ideas. In this context, columns, walls and beams can be thought of in terms of concepts of frequency, pattern, simplicity, regularity, randomness and complexity. As such, structure can be used to define space, create units, articulate circulation, suggest movement, or develop composition and modulations. In this way, it becomes inextricably linked to the very elements which create architecture, its quality and excitement.<sup>1</sup>

## The potential for structure to enrich architecture

Clark and Pause's statement above begins by describing the architectural qualities of structure and then suggests how structure might enrich architecture. But is such a positive attitude to structure realistic? What was the last building *you* experienced where structure either created the architecture or contributed a sense of excitement to it? Where do we find examples of structure playing such active architectural roles as defining space and modulating surfaces? And, how else might structure contribute architecturally? These questions set the agenda of this book, informing its focus and scope, and initiating an exploration of architecturally enriching structure.

Some readers may consider Clark and Pause's attitude towards structure as a fully integrated architectural element rather unrealistic. So often our day-to-day experience of structure can be described as unmemorable. In much of our built environment structure is either concealed or nondescript. Opaque façade panels or mirror-glass panes hide

structure located on a building's perimeter. Inside a building, suspended ceilings conceal beams, and vertical structural elements like columns, cross-bracing and structural walls are either enveloped within partition walls or else visually indistinguishable from them. Even if structure *is* exposed, often its repetitive and predictable configuration in plan and elevation, as well as its unrefined member and connection detailing, can rarely be described as 'creating architecture, its quality and excitement'.

Fortunately, in addition to these ubiquitous and bland structural encounters, sufficient precedents of positive structural contributions to architecture exist. They point towards bolder and more exciting possibilities and have convinced critical observers, like Clark and Pause and others, of the potential for structure to engage with architecture more actively and creatively. Peter Collins, the architectural theorist, shares similarly constructive convictions regarding structure's architectural roles. In concluding a discussion on eighteenth- and nineteenth-century Rationalism, he suggests:

However much the emphasis on structural expression may have been exaggerated in the past by a craving for ostentation, or reduced by the competing emphases on spatial effects, sculptural effects and new planning requirements, it is still potentially one of the most vigorous ideals of the modern age, and it would not be an exaggeration to say that it is the notion which offers the most fruitful prospects for the future development of modern architectural thought.<sup>2</sup>

Like the authors quoted above, I will also be looking beyond the physical necessity of structure towards its functional and aesthetic possibilities. Just because structure is essential



for built architecture, providing it with necessary stability, strength and stiffness, it does not have to be architecturally mute – unless of course its designers make that choice. This book provides many examples of structures ‘speaking’ and even ‘shouting’ in their architectural contexts. In these cases their designers, usually both architects and structural engineers, have made structural decisions that do not detract from but rather strengthen their architectural ideas and requirements. Structure no longer remains silent; it is a voice to be heard.

Where structure is given a voice, as illustrated in the following chapters, it contributes architectural meaning and richness, sometimes becoming the most significant of all architectural elements in a building. Endless opportunities exist for structure to enhance architecture and thereby enrich our architectural experiences. As designers we can allow structure to speak and to be heard; or, to change the metaphor, we can design structure so that its viewers not only see and experience it, but, due to its well-considered architectural qualities, are enticed into ‘reading’ it.

## Experiencing structure: reading and listening

Architects analyse structure by experiencing and reading it. In their succinct summary, Clarke and Pause suggest the ways structure might be read or analysed architecturally. In some architectural reviews of buildings, particularly where structure is exposed, structural readings are made. Although reviewers usually make little more than a passing comment, analysing structure in this way remains valid. The following two examples illustrate architecturally focused structural readings.

Fontein offers a reading of the interior structure of her School of Architecture building. She concentrates upon a single column, differentiated from others by virtue of its circular cross-section and increased height. She asserts that this column ‘plays a pivotal role in the building’ by marking and sheltering the intersection of two internal streets. It also connects that street junction to the school’s main collective space whose activities it both supports and obstructs. Ultimately it ‘establishes structure as a primary ordering device in the architecture of the School . . . and has the palpable effect of anchoring the life of the School’.<sup>3</sup>

LaVine tends towards less personified readings as he discerns significant architectural roles played by structure in his four house case-studies.<sup>4</sup> He notes how a ridge beam can symbolize the social centre of a house, and how a superstructure orders space by virtue of its regularity and hierarchy. In other examples, columns ‘signify human activities of special significance’ or ‘portray a mechanical idealism’. He reads walls as separating occupants from the outside world, and frames as ordering interior space. As he reads structure, each structural element is laden with meaning and makes an important architectural contribution.

For many, the reading of architecture is as natural as breathing. For example, Stan Allen comments on the Tama Art Library, designed by Toyo Ito, that

it is impossible not to read the arches as a sign, a reference to a recognizable form in the repertory of classical architecture. They *are* that, but they are many other things, too . . . Ito produces work that is richer and more nuanced precisely for its capacity to hold these multiple readings in a delicate equilibrium.<sup>5</sup>

All architectural readings incorporate a degree of subjectivity. To a certain extent, each reading is personal. It reflects the reader’s background and architectural knowledge. The quality of their experience of a building is another factor which depends on the duration of the visit and the depth of reflection during and after it.

The views of two or more readers are unlikely to be identical. Each person brings their own perspective. For example, an architect and structural engineer will read a structure quite differently. Each approaches it with his or her professional interest and concerns to the forefront. Whereas an architect might focus on how structure impacts the surrounding space, an engineer will most likely perceive structure as facilitating a load-path.

The discussion above considers structure as a passive architectural element – like a book waiting to be read. However, could it be that structure plays a more active role and actually speaks to us? So as well as reading structure must we also listen to it? According to Alain de Botton, we should.<sup>6</sup> To ease us into this possibly surprising idea, in his chapter ‘Talking buildings’ he reminds us how sculpture generates in us a thoughtful and responsive attitude towards objects. ‘The great abstract sculptures’, he says, ‘have

succeeded in speaking to us, in their particular dissociated language, of the important themes of our lives.<sup>7</sup> The argument continues that if objects in a gallery can speak, and even pencil squiggles on paper can convey emotions, such as peacefulness and confusion, how much more can buildings communicate? Buildings are therefore pregnant with expressive potential, as are their elements, including structure, and de Botton acknowledges this by suggesting that ‘we can be moved by a column that meets a roof with grace’.<sup>8</sup>

So, my architectural analyses of structure inevitably reflect who I am, how I read and listen to structure, and this is affected by my structural engineering background, my experience of teaching in a school of architecture, and my intense interest in how structure can enrich architecture.

Before commencing to read building structures and explore their architectural contributions, the next section clarifies the meaning of the book’s central focus – exposed structure.

## Structure and its degree of exposure

At this stage it is necessary to come to a common understanding of what constitutes structure, and to comment on aspects of its exposure. For the purpose of sensibly limiting the scope of the book, structure is taken to mean any structural element that bears load other than that arising from its self-weight or self-induced loads, like those from wind or snow.

This definition therefore excludes consideration of purely decorative elements without wanting to deny any significant architectural roles they might play. Imitative structure and authentic structural members that are not load-bearing, even though they might clearly express their materiality and display standard structural dimensions, lie outside the scope of this book. Examples of the latter category include exposed frameworks whose sole purpose is to contribute to a building’s composition, perhaps visually linking together disparate forms.

Although this discussion omits structure whose rationale is *solely* aesthetic, structural elements and details with minimal structural effectiveness *are* included. Structural details like the attached shafts on Gothic piers fall into this category. Even

though their architectural contribution may be seen as more aesthetic than structural, by increasing the cross-sectional area and depth of a pier, the details slightly increase its compression strength and overall stability.

Having established a working definition of structure, an explanation for the focus upon *exposed* structure is warranted and quite simple. Where structure is not exposed but concealed, perhaps hidden within wall cavities, screened by suspended ceilings or undifferentiated from partition walling, it possesses very limited opportunities to enrich architecture. In these situations, where the architecture must rely on other devices and elements for its qualities, any skeletal, wall-like or expressive structural qualities remain latent – structure cannot be read.

Architects take an unlimited number of approaches towards structural exposure. In its fully exposed state, the raw materiality of structure is visible, be it masonry, concrete, steel or natural timber. Even if coatings or claddings partially or fully veil structural members and their materiality, structural form can still play significant and expressive architectural roles. Steel structural members may be wrapped with corrosion and fire protection coatings and even cladding panels, but their structural forms can still enliven façades and interior spaces. Hence, in this book, *exposed* structure includes any visible structural forms, irrespective of whether their materiality is concealed.

This apparent preoccupation with exposed structure does not mean it is a requirement of exemplary architecture. Exposed structure has rightly been deemed inappropriate on many past occasions given the design ideals current at those times. Cowan gives examples of periods in architectural history, such as the Renaissance and the Baroque, when exposed structure would have detracted from the forms and embellished surfaces that designers were attempting to achieve.<sup>9</sup> Absence of exposed structure in contemporary buildings may also be completely defensible. For example, exterior exposed structure might compromise architectural forms exhibiting sculptural qualities and curved surfaces, and interior exposed structure would impact negatively upon an architectural goal of achieving spaces defined by pure planar surfaces.

Decisions regarding the extent to which structure should be exposed in an architectural design, if at all, are best made after revisiting the design concept and asking

whether exposed structure will enhance its realization. Then, irrespective of the answer, design ideas will be communicated with greater clarity. Structural exposure should therefore be limited to buildings where structure integrates with and clearly strengthens the expression of architectural ideas.

## Book outline

The following chapter analyses the structures of two contrasting buildings to set the scene for more focused and detailed explorations of many other buildings in the remainder of the book. Both buildings exemplify structure contributing architecturally in the context of specific architectural programmes. Exposed structure plays significant architectural roles on the exterior of the first building, while in the second, structure creates special interior spaces. Due to the inevitably limited range of architectural contributions illustrated by the two case-studies, the following chapters explore and illustrate exposed structure enriching specific areas of architecture in more detail.

Beginning with Chapter 3, chapter sequencing up to and including Chapter 9 reflects a typical progression of experiences when visiting a building. First, imagine approaching a building from a distance. When only architectural massing may be discerned, the diversity of relationship between architectural and structural form is explored. Then, in Chapter 4, drawing closer to the building, one observes structural elements enlivening façades in various ways, including forming surface patterns and textures, providing visual clues of entry, connecting exterior and interior architecture, and playing diverse expressive roles.

Having entered the building, the next three chapters consider relationships between the structure and interior architecture. Chapter 5 examines how structure enhances and, in some cases, defines building function. Structure maximizes planning flexibility, subdivides space to facilitate separate functions, and articulates circulation paths. Chapter 6 focuses on interior structure as an architectural element in its own right. It addresses the question of how structure enlivens and articulates interior spaces and surfaces. Examples

illustrate structure providing a wide range of surface and spatial qualities. Some interior structures read as responding to aspects such as a building's geometry or function, or, alternatively, expressing external factors like soil pressures or other site-specific characteristics.

Exploration of interior structure narrows in scope in Chapter 7 with an examination of structural detailing. After noting the importance of detailing being driven by a design concept, examples of expressive and responsive details are provided. They comprise two categories of details, one of which gains its inspiration from within the building, and the other from without. Some structural members are so elegantly detailed as to be considered objects of aesthetic delight, considerably increasing one's enjoyment and interest in architecture. A plethora of structural detailing languages with diverse architectural qualities strengthens designers' abilities to realize overarching architectural design concepts.

Chapter 8 investigates the relationship between structure and light, both natural and artificial. It illustrates structure's dual roles, as both a source and modifier of light, and introduces a number of different strategies designers use to maximize the ingress of light into buildings. Chapter 9 reflects on the symbolic and representational roles structure plays. Structure references naturally occurring objects like trees and processes such as erosion, as well as human artefacts, notions and experiences as diverse as oppression and humour.

Having completed explorations of exposed structure, Chapter 10 enters the world of hidden structure and contemplates its contribution to architecture, even though it is concealed. Then, in the following two chapters, the focus shifts from analysis of structure to design. Rather than analysing the roles of structure beyond load-bearing, the intent of Chapters 11 and 12 is to show how structure can reinforce architectural concepts, and realize specific architectural qualities.

The final chapter offers a brief distillation of the main themes that have emerged throughout the book – namely the transformative power of structure, the diversity with which it enriches architecture, and implications for the architectural and structural engineering professions.

## Notes

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6. A. de Botton, *The architecture of happiness*, London: Hamish Hamilton/Penguin, 2006.
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8. *Ibid.*, p. 98.
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two

# Two building studies

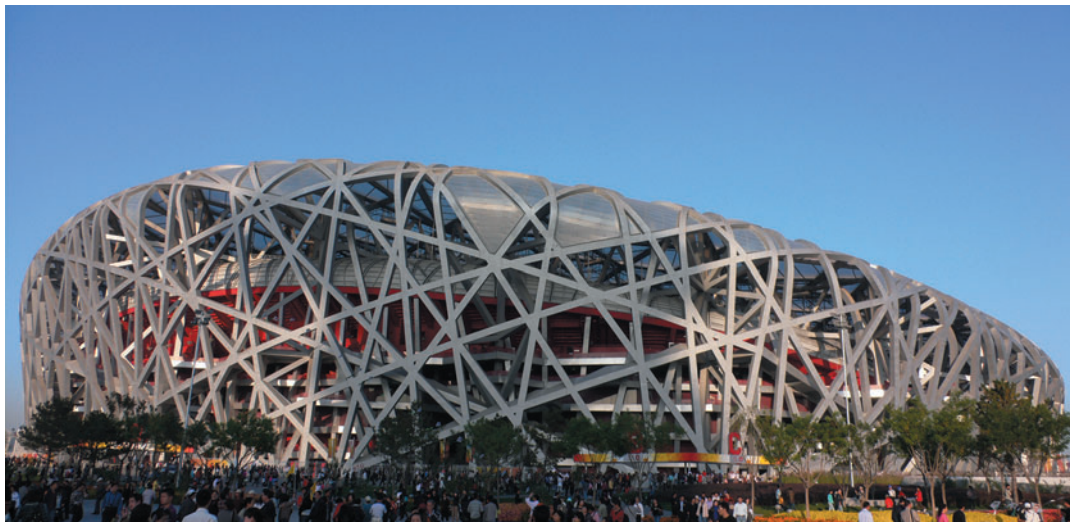
This chapter presents structural analyses of two very different buildings. Between them, they exemplify structure enriching most aspects and areas of architecture. These analyses introduce the many ways structure contributes to architecture and prepares the way for a more detailed investigation and categorization of the architectural potential of structure in subsequent chapters.

The following two case-studies illustrate the considered use of exposed structure in very different architectural contexts. First, the National Stadium, Beijing, displays an exuberant and chaotic exterior structure, but it is more muted when experienced from the interior. Exterior and interior expression reverses in the second building, the Baumschulenweg Crematorium. Within its formal minimalist exterior envelope, impressive exposed interior structure in the form of 'randomly placed' columns transforms the main space, leading to alternative architectural readings.

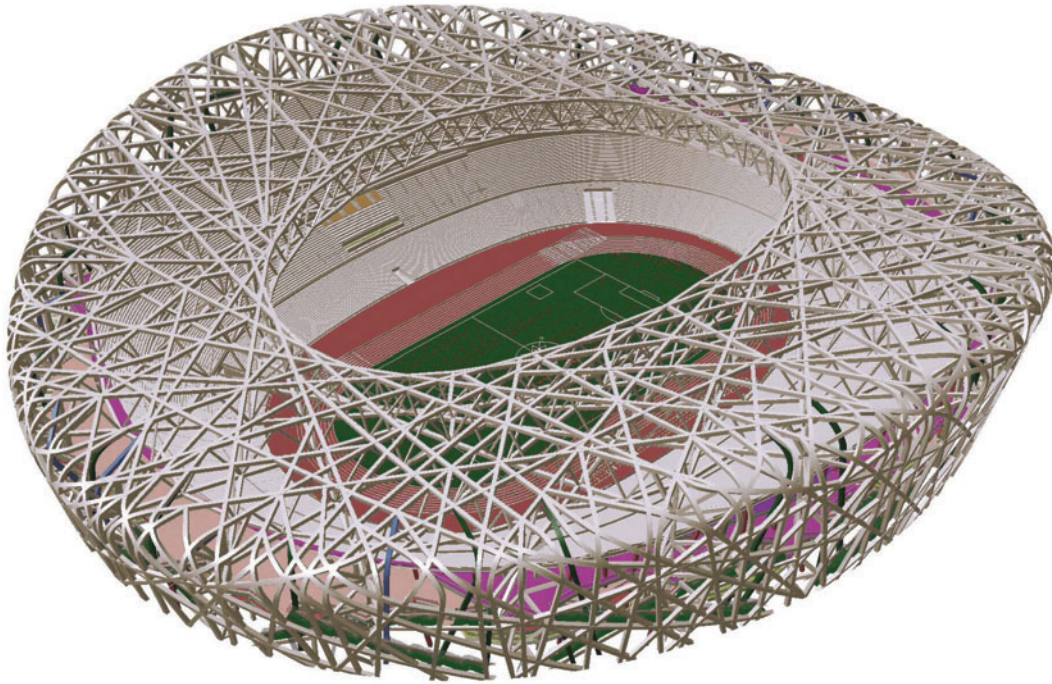
## National Stadium, Beijing

Built for the Beijing XXIXth Olympiad, which was held during August 2008, the National Stadium is the largest and most dominant building at the Olympic site. Accommodating 91,000 spectators during the Olympics, the oval-shaped stadium has a roof structure 313 m long by 266 m wide, including a large elliptical opening above the stadium pitch. A retractable roof was originally designed, but omitted at a late stage during the design process. The height of the saddle-shaped top surface varies from 40 m at its lowest point to the approximate height of a 20-storey building – 70 m – at its highest (Figure 2.1).

The rounded vessel-like form comprises two independent free-standing structures: an interior reinforced concrete bowl with its three tiers of sloping seating, and the perimeter and roof steel structure. The bowl structure is itself divided



**Figure 2.1**  
National Stadium, Beijing,  
China, Herzog & De Meuron,  
2008. An elevation of  
the stadium.

**Figure 2.2**

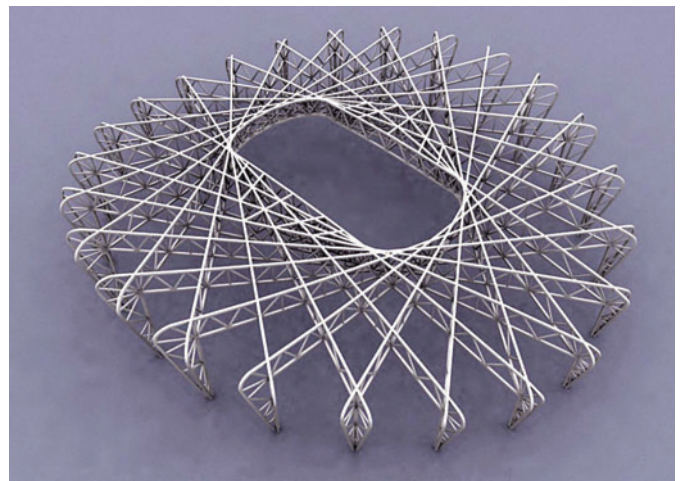
The perimeter steel structure wraps around the inner concrete bowl (Arup).

into six structurally independent segments separated by 200 mm-wide gaps for seismic and thermal movements. These structures are frame structures, consisting of beams and columns interconnected by rigid joints. Lateral or horizontal loads arising from wind and earthquake are mainly resisted by structural walls forming the two lift cores of each segment. The roof is clad by two tension membranes supported by the perimeter and roof steel structure. An outer transparent ETFE single-layer provides weather protection to the stands, while a lower PTFE membrane offers shade and improved acoustics.

The perimeter steel structure defines the extent and shape of the building as it wraps around it (Figure 2.2). However, unlike most stadiums with exposed structure, from most vantage points both outside and within the structural rationale, if any, is not at all apparent. How does this chaotic assemblage of inclined members that become curved tangles at roof level possibly constitute a roof structure? How can such an apparently irrational configuration of structural members provide a roof that cantilevers over 40 m from its perimeter to the edge of the internal opening? Is this a case where so much structure is thrown into a building in the absence of structural rationality that highly sophisticated structural engineering analyses indicate the structure will somehow stand up? The answers to these questions

can hardly be answered without recourse to engineering drawings. They reveal a most unexpected yet conceptually simple structural solution (Figures 2.3 and 2.4).

Perimeter structural chaos effectively conceals a series of twenty-four symmetrically positioned portal frames. Portal frames, just one level of complexity beyond the most basic of structural systems, the post-and-beam, are responsible for supporting the whole roof. Their presence is even more

**Figure 2.3**

A physical model of the perimeter steel and roof gravity-resisting portal frame structure (Arup).



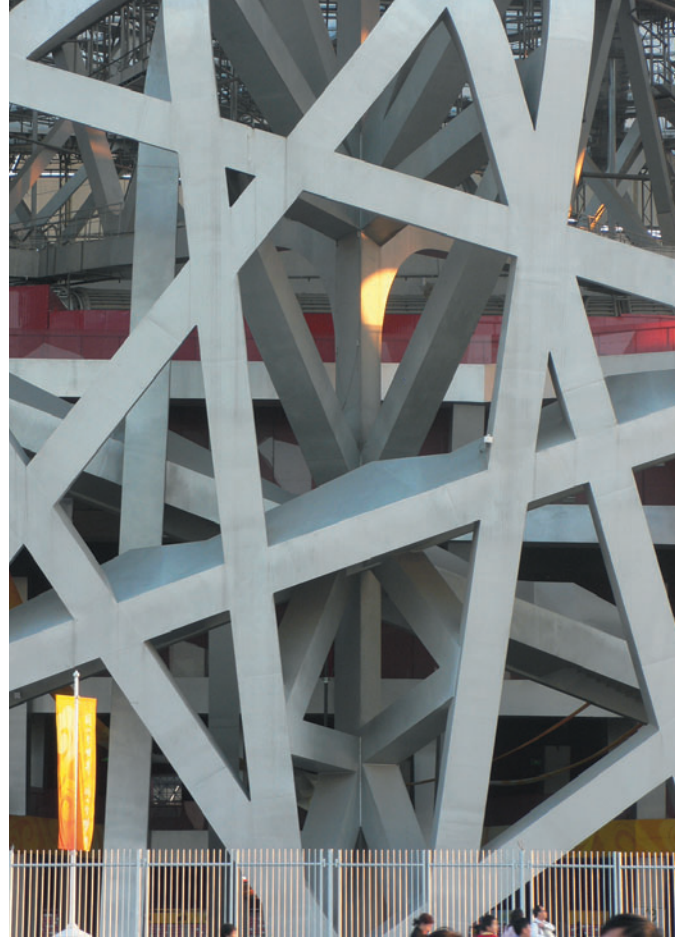
**Figure 2.4**

The bottom chords of the portal girders can be seen from the seating bowl.

surprising given their general relegation by architects to structure less elegant constructions, like light-industrial buildings. Admittedly, these portal frames are not the normal run-of-the-mill type. Detailed as trusses, and 12 m deep, they interconnect to support each other and form a three-dimensional truss network. Each column, V-shaped in plan, deepens from a pin joint at its base to reach the 12 m depth before bending over to become a portal frame girder (Figures 2.5 and 2.6). This is the roof structure, designed for gravity loads, vertical loads from wind, and earthquake loads.

The horizontal load resistance of the free-standing perimeter and roof structure is also another puzzle inviting resolution. Damage to the portal frames must be prevented during a large earthquake. The stability of the whole roof structure cannot be jeopardized. And yet there are no visible shear walls, bays of conventional cross-bracing or obvious moment frames – the three most conventional seismic force-resisting systems. However, we can discern within the irregularity of the layout of façade members patterns of triangulation, albeit not from any textbook. This irregular triangulated structure, which seems to be a consequence of structural randomization, provides sufficient strength and stiffness to satisfy the demanding engineering design criteria.

Structural elements visually dominate the exterior of this building by their random and dynamic arrangement. Rather than relying upon monumentality conferred by massive structural walls or columns, the modestly sized members exude expressive qualities due to their geometrical configuration. At least on the outer structural layer no vertical nor horizontal members are found. Orthogonality has been



**Figure 2.5**

A view of a V-shaped truss-column near its base.



**Figure 2.6**

Horizontal and diagonal members of portal girders are visible beyond the upper curved structure.



**Figure 2.7**

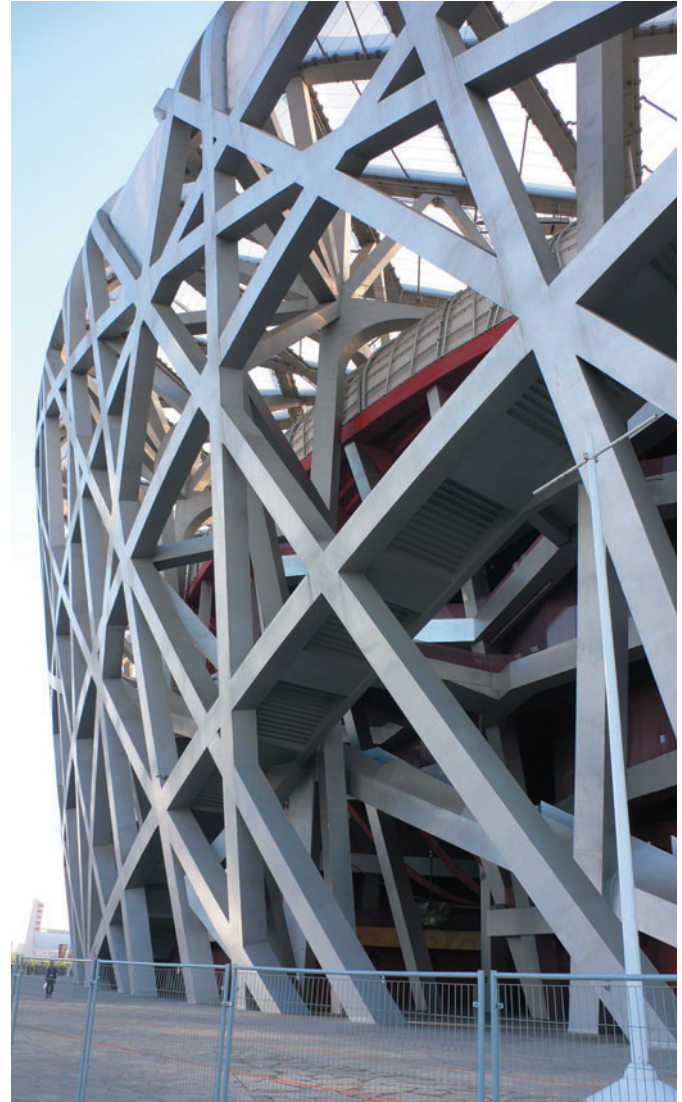
Columns supporting the concrete bowl are also inclined.

banished entirely from the perimeter structure, but it is still able to fulfil its load-bearing roles (and others). For example, its bewildering number and orientation of members act to screen the seating bowl, whose visual presence is enhanced by red-painted exterior surfaces. The 'screen', up to 12 m deep, is also very porous, if not welcoming. A lack of perimeter structural barriers means there can be many possible entrances.

A potential danger of expressing such dynamic perimeter structure is that more conventional interior structure, by comparison, could be considered an anticlimax. This has been avoided by the inclination of columns around both the perimeter and inner edges of the concrete bowl (Figure 2.7). Steel and concrete members speak the same dynamic language so there is no aesthetic disjuncture between these two structures.

As well as the perimeter structure functioning as a fully load-bearing assemblage and an expressive façade with screening qualities, it hosts most of the stadium's vertical circulation in the form of stairs. The stairs are integral with the least-inclined sloping members which conceal them from view (Figure 2.8). As they rise, the stairs snake around and through the structure. This strategy of embedding circulation within the structural width or depth is observed in other buildings too, such as the Sainsbury Centre, whose perimeter structure along its sides provides space for stairs and other functions (see Figure 5.12).

One of the architectural characteristics of the exposed steel structure that requires comment is its detailing: that is, the form and finishing of the structural members and their



**Figure 2.8**

A flight of stairs with a visible soffit fully integrated with an inclined perimeter member.

connections. The most significant aspect of detailing is that all exposed members, square steel box sections, have the same external dimension of 1.2 m × 1.2 m. The tremendous variation in forces within members is economically accommodated by adjusting the wall thicknesses of the sections. Plate thickness varies from 10 mm to 100 mm, but the resulting variation in strength is not apparent.

So, not only is there no visual hierarchy of strength or structural importance in the structural members, but since every member, whether primary, secondary or tertiary, has the same dimensions, there is no structural hierarchy *at all*.