## Table of Contents

* Acknowledgements ix 
* Glossary xiii 

### 1 Introduction 1 
1.1 OEM Model and Manufacturing Strategy 2 
1.2 Analysis Framework 4 
1.3 Organization of this Volume 5 

### 2 Automation and Robotics in Building Component Manufacturing 7 
2.1 Brickwork- and Ceramics-Based Components 8 
2.1.1 History and Techniques of Brick and Ceramic Parts Production 8 
2.1.2 Keys and Figures 9 
2.1.3 Classification of Ceramic Construction Elements and Brickwork Products 9 
2.1.4 Manufacturing Methods 10 
2.1.5 Possibilities for Industrial Customization 12 
2.1.6 End-Ef fectors and Automated Processes 12 
2.1.7 Factory Layouts 20 
2.1.8 Emerging Techniques in the Field 22 
2.1.9 End-of-Life Strategies 24 

2.2 Concrete-Based Components 25 
2.2.1 History and Techniques of Concrete Prefabrication 26 
2.2.2 Keys and Figures 27 
2.2.3 Classification of Precast Concrete Products 28 
2.2.4 Manufacturing Methods for Precast Concrete 30 
2.2.5 Possibilities for Industrial Customization 32 
2.2.6 Equipment and End-Ef fectors for Automated Production 33
2.2.7 Factory Production Layouts 36
2.2.8 Emerging Techniques in the Field 36
2.2.9 End-of-Life Strategies 43

2.3 Wood-Based Components 43
  2.3.1 History and Techniques of Wood/Timber Construction and Prefabrication 43
  2.3.2 Keys and Figures 44
  2.3.3 Classification of Products 44
  2.3.4 Manufacturing Methods 46
  2.3.5 Possibilities for Industrial Customization 47
  2.3.6 End-Effectors and Automated Processes 49
  2.3.7 Factory Production Layouts 52
  2.3.8 Emerging Techniques in the Field of Timber Prefabrication 52
  2.3.9 End-of-Life Strategies 54

2.4 Steel-Based Components 54
  2.4.1 History and Techniques of Steel Production 54
  2.4.2 Keys and Figures 55
  2.4.3 Classification of Products 55
  2.4.4 Manufacturing Methods: Steel Elements 57
  2.4.5 Possibilities for Industrial Customization 60
  2.4.6 End-Effectors and Automated Processes 61
  2.4.7 Factory Production Layouts 62
  2.4.8 Emerging Techniques in the Field 63
  2.4.9 End-of-Life Strategies 63

3 Building Module Manufacturing ........................................... 66

4 Comparison of Large-Scale Building Manufacturing in Different Countries ........................................... 72
  4.1 Germany ................................................................. 73
   4.1.1 Wood-Based Housing Prefabrication in Germany 73
   4.1.2 Steel-Based Building Prefabrication in Germany 76
  4.2 United Kingdom ....................................................... 82
   4.2.1 History ............................................................ 82
   4.2.2 General Overview .............................................. 83
   4.2.3 Companies ...................................................... 84
   4.2.4 Manufacturing Methods ..................................... 87
   4.2.5 Conclusion ..................................................... 87
  4.3 Spain ................................................................. 88
   4.3.1 History ............................................................ 88
   4.3.2 General Overview .............................................. 88
   4.3.3 Companies ...................................................... 88
   4.3.4 Manufacturing Methods ..................................... 88
   4.3.5 Conclusion ..................................................... 89
  4.4 China ................................................................. 89
   4.4.1 History ............................................................ 89
4.4.2 General Overview 89
4.4.3 Companies 89
4.4.4 Manufacturing Method 91
4.4.5 Conclusion 92

5  Large-Scale Building System Manufacturing in Japan ................. 93
5.1 Background, Development, and Strategy of the Industry 94
5.1.1 Overview Companies (Turnover, Output, Employees, Prices, Factories) 94
5.1.2 Japan’s Prefabrication Industry Today and Tomorrow 96
5.1.3 Karakuri Technology Diffusion in Japan 98
5.1.4 Influences of Local and Cultural Specifics and Disasters 99
5.1.5 Roots in Chemicals, Electronics, and the Automotive Industry 101
5.1.6 Drivers for Prefabrication in Japan 103
5.1.7 First Approaches to Mass Production: Premos Home 104
5.1.8 Sekisui Heim’s M1 107
5.1.9 From Japan’s Traditional Organizational Culture towards TPS and Toyota Home 109
5.1.10 Automated and Robotized Production as Sales Argument 110
5.1.11 Sekisui Heim – ERP Systems for the Control of Increasing Complexity 111
5.1.12 Timeline of Evolution of Prefabrication in Japan 112
5.2 Robot-Oriented Design and Management Strategies Used in the Japanese Prefabrication Industry 116
5.2.1 The Idea of Robot-Oriented Design and Management 116
5.2.2 Complementarity as a Key Element in the Success of Automated Prefabrication in Japan 116
5.2.3 Robotic Logistics-Oriented Design 117
5.2.4 Robotic Assembly–Oriented Design 118
5.2.5 Degree of Structuring/Automation of Off-Site and On-Site Environments 119
5.2.6 OEM-like Integration Structure 121
5.2.7 Modular Coordination 121
5.2.8 Control of Variation by Platform- and Same-Parts Strategies 121
5.2.9 Linking of Customer and Manufacturing System 122
5.2.10 Innovation and R&D Capability as Key Elements of the Business Strategy 125
5.2.11 Performance Multiplication Effect 126
5.3 The Manufacturing Process 128
5.3.1 Product Variety and Types of Prefabrication 129
5.3.2 Production Process Explained by Sekisui’s and Toyota’s Unit Method 129
5.3.3 Factory Layouts and Process Design Strategies 135
5.4 Analysis of Selected Companies and Their Manufacturing Systems

<table>
<thead>
<tr>
<th>Subsection</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4.1 Sekisui House (Fully Panelized Steel Kit)</td>
<td>149</td>
</tr>
<tr>
<td>5.4.2 Daiwa House (Steel Frame Combined with Panels)</td>
<td>159</td>
</tr>
<tr>
<td>5.4.3 Pana Home (Steel Panels Combined with Steel Components)</td>
<td>162</td>
</tr>
<tr>
<td>5.4.4 Sanyo Homes Corporation (Steel Frame Combined with Panels)</td>
<td>166</td>
</tr>
<tr>
<td>5.4.5 Asahi Kasei – Hebel House Homes (Steel Frame Combined with Aerated Concrete Panels)</td>
<td>168</td>
</tr>
<tr>
<td>5.4.6 Misawa Homes Sub- and Mini-Assembly Units (Wood Panels)</td>
<td>171</td>
</tr>
<tr>
<td>5.4.7 Mitsui Home (Wood Panels)</td>
<td>174</td>
</tr>
<tr>
<td>5.4.8 Tama Home (Wooden Frame Combined with Panels)</td>
<td>176</td>
</tr>
<tr>
<td>5.4.9 Muji House (Wooden Frame Combined with Panels)</td>
<td>181</td>
</tr>
<tr>
<td>5.4.10 Sekisui Heim (Steel Units)</td>
<td>185</td>
</tr>
<tr>
<td>5.4.11 Toyota Home (Steel Units)</td>
<td>198</td>
</tr>
<tr>
<td>5.4.12 Misawa Homes Hybrid (Steel Units)</td>
<td>201</td>
</tr>
<tr>
<td>5.4.13 Sekisui Heim Two-U Home (Wood Units)</td>
<td>206</td>
</tr>
</tbody>
</table>

5.5 Evolving Tendencies in the Evolution of the Japanese Prefabrication Industry

<table>
<thead>
<tr>
<th>Subsection</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5.1 Advanced Product Service Systems</td>
<td>207</td>
</tr>
<tr>
<td>5.5.2 Prefabrication Industry as Part of a Large-Scale Disaster Management Strategy</td>
<td>208</td>
</tr>
<tr>
<td>5.5.3 Extending the Value Chain through the Development of Prefabricated, Sustainable High-Tech Settlements</td>
<td>211</td>
</tr>
<tr>
<td>5.5.4 Reverse Innovation: Mass-Customized Housing Production as a Prototype for Future Manufacturing Systems</td>
<td>216</td>
</tr>
</tbody>
</table>

References                                                                 | 225  |
Index                                                                       | 233  |