



MODERNISATION, MECHANISATION & INDUSTRIALISATION of Concrete Structures

Edited by
Kim S. Elliott
and **Zuhairi Abd. Hamid**

WILEY Blackwell

MODERNISATION, MECHANISATION AND INDUSTRIALISATION OF CONCRETE STRUCTURES

Edited by

Kim S. Elliott

Precast Consultant, Derbyshire, UK

Zuhairi Abd. Hamid

*Construction Research Institute of Malaysia (CREAM),
Kuala Lumpur, Malaysia*

WILEY Blackwell

This edition first published 2017
© 2017 by John Wiley & Sons Ltd

Registered office

John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ,
United Kingdom.

Editorial offices:

9600 Garsington Road, Oxford, OX4 2DQ, United Kingdom.

The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom.

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com/wiley-blackwell.

The right of the author to be identified as the author of this work has been asserted in accordance with the UK Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book.

Limit of Liability/Disclaimer of Warranty: While the publisher and author(s) have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. It is sold on the understanding that the publisher is not engaged in rendering professional services and neither the publisher nor the author shall be liable for damages arising herefrom. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

Library of Congress Cataloging-in-Publication Data:

Names: Elliott, Kim S., editor. | Hamid, Zuhairi Abd., editor.

Title: Modernisation, mechanisation and industrialisation of concrete structures / edited by Kim S. Elliott, Zuhairi Abd. Hamid.

Description: Chichester, UK ; Hoboken, NJ : John Wiley & Sons, 2017. |

Includes bibliographical references and index.

Identifiers: LCCN 2016044825 | ISBN 9781118876497 (cloth) | ISBN 9781118876510 (epub)

Subjects: LCSH: Concrete construction industry.

Classification: LCC HD9622.A2 M63 2017 | DDC 338.4/76241834 – dc23 LC record available at <https://lcn.loc.gov/2016044825>

A catalogue record for this book is available from the British Library.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Cover Design: Wiley

Cover Image: Background image: Smileyjoanne/Gettyimages

Top landscape image: wsfurlan/Gettyimages

Left bottom image: Highly automated plant in 2013/RIB SAA Software Engineering GmbH

Centre bottom image: bikeriderlondon/Shutterstock

Right bottom image: Canadastock/Shutterstock

Set in 10/12pt MinionPro by SPi Global, Chennai, India

Printed and bound in Malaysia by Vivar Printing Sdn Bhd

10 9 8 7 6 5 4 3 2 1

MODERNISATION, MECHANISATION AND INDUSTRIALISATION OF CONCRETE STRUCTURES

About the Editors

Kim Stephen Elliott, Precast Consultant, Derbyshire, UK

Kim Stephen Elliott is a consultant to the precast industry in the UK and Malaysia. He was Senior Lecturer in the School of Civil Engineering at Nottingham University, UK from 1987–2010 and was formerly at Trent Concrete Structures Ltd. UK. He is a member of fib Commission 6 on Prefabrication where he has made contributions to six manuals and technical bulletins, and is the author of *Multi-Storey Precast Concrete Frame Structures* (1996, 2013) and *Precast Concrete Structures* (2002, 2016) and co-authored *The Concrete Centre's Economic Concrete Frames Manual* (2009). He was Chairman of the European research project COST C1 on Semi-Rigid Connection in Precast Structures (1992–1999). He has lectured on precast concrete structures 45 times in 16 countries worldwide (including Malaysia, Singapore, Korea, Brazil, South Africa, Barbados Austria, Poland, Portugal, Spain, Scandinavia and Australia) and at 30 UK universities.

Zuhairi Abd Hamid, Construction Research Institute of Malaysia (CREAM), Kuala Lumpur, Malaysia

Zuhairi Abd. Hamid has more than 32 years of experience in the construction industry. His expertise lies in structural dynamics, industrialised building systems, strategic IT in construction and Facilities Management. He is active in engineering education and research and has been appointed by universities in various capacities; from Adjunct Professor, Research Fellow and member of the industry Advisory Panel. He is the Regional Director of South East Asia and Guest Member for the UN support International Council for Research and Innovation in Building and Construction (CIB). Currently, as the Executive Director at CREAM, he actively engages in construction research for industrial publications in Malaysia.

Notes on Contributors

Ahmad Hazim Abdul Rahim, Construction Research Institute of Malaysia (CREAM), Kuala Lumpur, Malaysia

Ahmad Hazim Abdul Rahim is currently the Manager at Construction Research Institute of Malaysia. He has been involved in research and development (R&D) fields in construction and civil engineering for more than 15 years. He currently heads the structural engineering laboratory at CREAM, an ISO/IEC 17025 accredited laboratory and in charge of the technical and quality aspect of the day to day operational of the laboratory. He holds a B. Eng (Hons) in Civil Engineering and completed his Masters in Engineering Science in 2007. His area of interests is conformity assessment of structural component, full-scale structural test and construction materials testing and evaluation. He has published various publications ranging from books to peer-reviewed journals, technical papers, proceedings and articles.

Foo Chee Hung, Construction Research Institute of Malaysia (CREAM), Kuala Lumpur, Malaysia

Foo Chee Hung is a researcher from the Construction Research Institute of Malaysia (CREAM) – a research arm under the Construction Industry Development Board Malaysia (CIDB). He is currently the Head of Consultancy and Technical Opinion Unit.

He obtained both his first (Environmental Engineering) and master (SHE Engineering) degree at the University of Malaya. He then further pursued his PhD (Urban Engineering) in the University of Tokyo. His research interest is in sustainability, affordable housing, green building, building quality assessment, Industrialized Building System (IBS), and urban ecosystem.

He is a member of the Institution of Engineers Malaysia (IEM), and the GreenRE manager.

Gan Hock Beng, G&A Architect

Gan Hock Beng is the Founder of G&A Architect. He is currently engaged in a number of residential and commercial projects in Georgetown, Penang. The projects he has worked on include landmarks like Times Square, Moonlight Bay, University Place, The View, etc. He has been the invited speaker at conferences organized by the Singapore Ministry of Housing, and the South Korea Ministry of Housing. He was given the award of “Most Innovative Design” in a competition organized by the Ministry of Housing Malaysia.

Susanne Schachinger, Precast Software Engineering, Wals-Siezenheim, Austria

Susanne Schachinger is an International Sales Representative at Precast Software Engineering. As a co-author she brings in expertise from her daily work with precast companies in various countries. University studies in Graz (Austria), Volgograd (Russia) and Prague (Czech Republic) led her to the consumer goods industry before she joined Precast Software Engineering in 2011. She represents the company at IPHA (International Prestressed Hollowcore Association).

Thomas Leopoldseder, Precast Software Engineering, Wals-Siezenheim, Austria

Thomas Leopoldseder works as an international BIM Consultant and Product Manager of TIM (Technical Information Manager) at Precast Software Engineering in Austria (Part of Nemetschek Group) which is developing high-end CAD and BIM solutions for the precast industry. After studying at the Vienna University of Economics and Business, he first worked as an IT consultant and then at various levels (CFO, General Manager) in the precast industry. He is now one of the leading experts in BIM solutions concerning the precast industry.

Robert Neubauer, SAA Software Engineering GmbH, Austria

Neubauer has been a Managing Partner at SAA Software Engineering in Vienna, Austria since 1999, leading the development of CAM and Control-Software for the precast concrete manufacturing industry. In 1986 he was engaged in automation in the construction industry, realizing the first control- and master-computer-software for the first automated precast concrete plant. After graduating in mechanical engineering at the Technical University of Vienna in 1993 he was previously at Ainedter Industry Automation and at Sommer Automatisierungstechnik (Austria).

During the past 30 years, Mr Neubauer has been working on automation in the prefabrication industry for construction, developing and conducting development for new solutions, collaborating with different vendors for plants and machinery and leading committees. At the end of 2015, SAA merged with RIB Software AG/Germany,

and as Managing Partner, he is accompanying RIB SAA Software Engineering GmbH into a BIM-5D integrated future for smart production of construction systems.

Gerhard Girmscheid, ETH, Swiss Federal Institute of Technology, Zurich, Switzerland

Gerhard Girmscheid, studied construction engineering in Darmstadt (Germany), occupying management posts at German and American construction enterprises, involving assignments abroad that included major construction sites in Egypt and Thailand, as well as the fourth tunnel tube under the River Elbe in Hamburg. Since 1996, he has been Professor of Construction Business Management and Construction Process Engineering at ETH Zurich (Switzerland). He was recently awarded emeritus status.

In research and teaching, Professor Girmscheid focuses on construction processes, and strategic and operational construction enterprise management. His SysBau® research targets improved, more efficient, and new sustainable life cycle-oriented construction processes and portfolios aimed at strengthening the innovative and competitive abilities of construction industry providers. His research activities have produced numerous dissertations and research reports, together with more than 100 peer-reviewed specialist publications. He has written several books on construction enterprise and process management.

He sits on the Board of Directors of general contracting and property company Priora AG, and prefabrication specialists Müller-Stein AG. He also manages CTT-Consulting in Lenzburg (Switzerland), advising companies and training staff on improving bidding and execution processes, managing claims, and implementation.

Julia Selberherr, ETH, Swiss Federal Institute of Technology, Zurich, Switzerland

Julia Selberherr received her Civil Engineering diploma from the Vienna University of Technology in 2009 as well as her Business Management diploma from the Vienna University of Economics and Business in 2010. She then conducted a research project focused on the provision of sustainable life-cycle offers in the building industry at the Institute of Construction and Infrastructure Management at the Swiss Federal Institute of Technology. Her research is dedicated to the optimization of operational and strategic processes across a building's life cycle through the integrated cooperation of the key stakeholder using customizable industrial production technologies. She has contributed several international journal papers and conference publications establishing innovative approaches to a life-cycle service provision in the building industry. Dr. Selberherr completed the project with the development of a new business model in her PhD thesis in 2014. As a renowned expert in the field of organization and process design for sustainable building, she is currently working as a senior consultant in the real estate industry in Zurich.

Preface

The modernisation and industrialisation of concrete structures, through the means of prefabrication of concrete elements together with the computerization of design, detailing and scheduling, is taking an awful long time to come to fruition. The once aspired paperless journey from the architect's concept to the factory floor and beyond is gradually closing in. Critics may cite the post WW2 boom in the construction of high-rise apartment buildings in part of northern and eastern Europe as 70-year-old industrialisation, but it was nothing more than concrete construction on such a large scale that it was thought to be "industrialisation" - the linear and manual processes of design, detailing, scheduling and manufacture were no more advanced than early twentieth-century construction.

There was little automation in the concrete industry until the combined technologies of long line pretensioning of steel wires and the extrusion of semi-dry concrete lead to such elements as prefabricated hollow core floor slabs in the 1950s. Except for a number of step-change advancements such as (i) the hydraulic extruder, (ii) the "carousel" method of casting and moving beds, and (iii) higher performance/strength concrete, hollow core units are still made in much the same way. Changes came in the 1970s after the Japanese taught the Europeans and Americans how they made cars - with forward/sideways/up/down production of the individual components leading to the whole. We now see such automotive methods used in the carousel table-top production of concrete wall panels and façade units, and together with CAD/CAM, Auto-CAD systems, TIM scheduling, and the automated supply of drawings and component schedules to the factories, the age of modernisation, mechanisation and industrialization (MMI) of concrete structures has finally arrived.

Architects and consulting engineers are still wary of the term "building systems", with images of shoe-box designs typified by the 1960s national building frames, carelessly exploiting modularization and standardisation possible in precast concrete. Today fully bespoke and individually tailored precast concrete elements can be designed and erected into many diverse forms to cover the huge spectrum of building architecture - all of which are industrialised by MMI. The term IBS (Industrialised Building Systems) can now be used with architectural and engineering freedom, for example, Sydney Opera House's torus-shaped prestressed beams and tiled facades. During a precast concrete workshop in Singapore in the mid 2000s an architect asked (something like) "what are the major features that distinguish precast concrete

buildings from cast *insitu*". The reply, given by one of the authors of this book, was that "precast is used when the client or architect sees concrete as something special – both structurally of aesthetically, and maximises the operations that you can only carry out in the controlled environment of a factory", and so on.

The move to increased automation in the factory has coincided with the automation of spatial design – the use of three-dimensional co-ordinate orthogonal geometry, well known to school boys, to build 3D models from rectilinear 2D building plans and elevations, now known as BIM (Building Information Modelling) and the accompanying software for the design and detailing of precast (and steel, timber, etc.) structures. Professor C. J. Anumba of Pennsylvania State University addressed a Seminar & Workshop on the Developments and Future Directions in BIM (Kuala Lumpur, 2012) thus *Developments in BIM have resulted in significant industry interest and uptake. Most new building projects are dependent on BIM for resolving coordination, schedule, integration, estimating and other functions. Advances in information and communications technologies are continuing to open up new opportunities and applications. As such, more needs to be done to fully exploit the potential of these technologies and to meet the requirements of increasingly complex projects.*

Against this background of MMI and BIM the aims and objectives of this book were, as conceived by Dr Zuhairi, from CREAM (Construction Research Institute of Malaysia), to provide a concise text to show how the modernisation, mechanisation and industrialisation of prefabricated concrete structures can be achieved through the knowledge of best practice, information modelling, and the procedures and management of factory engineered concrete products and systems. The main objectives were to:

- i. show how previous R&D and present design and manufacturing techniques can be best exploited for the construction of modern precast concrete structures,
- ii. show how the IBS ethos can control the supply chain from the client to sub-contractors, and can best utilise BIM methods and design/detailing software,
- iii. introduce the best concepts of automation and robotics in concrete production, and
- iv. exploit the industrialisation of off-site production and on-site processes, including low cost housing in south east Asia.

The authors were selected from the UK, Germany, Switzerland, Austria and Malaysia, each having expertise and a (fairly) long history in items (i) to (iv). Of significance was Mr Robert Neubauer of SAA Software Engineering, a production/structural engineer able to harmonise the requirements of prefabrication in design with automated production; Mr Thomas Leopoldseeder and Ms Suzanna Schachinger, of Precast Software, with abilities to exploit BIM and related software to the full advantage of precast solutions; Prof Gerhard Girmsheid and Dr Julia Selberherr, of ETH (Swiss Federal Institute of Technology, Zurich) specialising in the respective roles of industrialisation of off-site and on-site construction; CREAM consultants Dr Zuhairi, Mr Gan Hock Beng, Foo Chee Hung and Ahmad Hazim Abdul Rahim responsible for the technical advancements of IBS for low-cost housing; and Dr Kim S Elliott, precast consultant, summarising the modernisation and optimization of precast and prestressed elements and structures.

This book is divided into three key themes, as reflected in its title:

Part 1: MODERNISATION

- Chapter 1: Historical and Chronological Development of Precast Concrete Structures
- Chapter 2: Industrial Building Systems (IBS) Project Implementation
- Chapter 3: Best Practice and Lessons Learned in IBS Design, Detailing and Construction

Part 2: MECHANISATION AND AUTOMATION

- Chapter 4: Research and Development Towards the Optimisation of Precast Concrete Structures
- Chapter 5: Building Information Modelling (BIM) and Software for the Design and Detailing of Precast Structures
- Chapter 6: Mechanisation, Automation and Robotics in Concrete Production

Part 3: INDUSTRIALISATION

- Chapter 7: Lean Construction, Part 1 – Industrialisation of On-Site Production Processes
- Chapter 8: Lean Construction, Part 2 – Planning and Execution of Construction Processes
- Chapter 9: New Cooperative Business Model - Industrialisation of Off-Site Production
- Chapter 10: Retrospective View and Future Initiatives in IBS and MMI
- Chapter 11: Affordable and Quality Housing Through Mechanization, Modernization and Mass Customization

A number of chapters address the issues of modern housing. Concrete has great potential to offer building and housing construction works towards improving the function, value, and whole life performance, especially in the era where quick, efficient, and inexpensive construction and delivery are becoming the necessity and desires of the societies. Precast concrete construction is a technology that possesses the potential to eliminate building site inconveniences, reducing the lapsed time and cost of construction, and contributing to an end product that conforms to the required standards and codes.

However, buildings and houses produced with such technology have a rigid structure, an interlocking plan, and predetermined functions, where very few of them are sufficiently open plan to enable retrofitting and reconfigurations to be made quickly, economically, and repeatedly. Moreover, various negative perceptions, opinions, and images spring to mind when considering the concept of prefabrication and standardisation in housing, as a result of a number of buildings constructed in the past making use of prefabrication were judged to be of poor quality. This book will provide insight to builders of the potential for building and housing design system that makes use of the prefabrication construction to produce a variety of housing design options that meet possible user requirements not yet identified at the design stage, while retaining principal uniformity to facilitate the execution of simple but accurate construction with a minimal initial cost.

It is believed that only by having combined design and construction systems that take advantage of mass production and mass customisation, the efficient design of offices, parking structures, shopping and residential buildings, coupled with housing affordability and liveability can be achieved. A home that can be altered with minimum effort and expense at a time of change in the lives of its owners is a home that evolves with the lifecycles of its household rather than becoming rigidly obsolete in the conventional manner. As such, the affordable housing needs to be designed in such a way that it is economically and easily adjustable, as well as adheres to the context of contemporary technology, climate adaptation, and cultural responses.

Contents

<i>About the Editors</i>	xi
<i>Notes on Contributors</i>	xiii
<i>Preface</i>	xvii
Part 1 Modernisation of Precast Concrete Structures	1
1 Historical and Chronological Development of Precast Concrete Structures	3
<i>Kim S. Elliott</i>	
1.1 The five periods of development and optimisation	3
1.2 Developing years and the standardisation period	26
1.3 Optimisation and the lightweight period	34
1.3.1 Minimising beam and slab depths and structural zones	34
1.3.2 Orientation rule	38
1.3.3 Composite and continuous floor slabs	38
1.3.4 Composite and continuous internal beams	43
1.4 The thermal mass period	46
1.4.1 Background to fabric energy storage in precast framed and wall structures	46
1.4.2 Admittance and cooling capacity	48
1.4.3 Thermal resistance and U-values for precast ground and suspended floors	51
1.4.4 Conclusion to FES, cooling and thermal transmission	58
References	59
2 Industrial Building Systems (IBS) Project Implementation	61
<i>Kim S. Elliott</i>	
2.1 Introduction	61
2.1.1 Definition of IBS	63
2.1.2 Advantages of IBS	64
2.1.3 Sustainability of IBS	67
2.1.4 Drawbacks of IBS	68
2.2 Routes to IBS procurement	69
2.2.1 Definitions	69
2.2.2 Preliminaries	70
2.2.3 Project design stages	71

2.2.4	Design and detailing practice	79
2.2.5	Structural design calculations and project drawings	80
2.2.6	Component schedules and the engineer's instructions to factory and site	87
2.3	Precast concrete IBS solution to seven-storey skeletal frame	89
2.4	Manufacture of precast concrete components and ancillaries	93
2.4.1	Requirements and potential for automation	93
2.4.2	Floor slabs by slip-forming and extrusion techniques	93
2.4.3	Comparisons of slip-forming and extrusion techniques, and r.c. slabs	102
2.4.4	Hydraulic extruder	102
2.4.5	Reinforced hollow core slabs	103
2.4.6	Automated embedment machines for mesh and fabrics in double-tee slabs	106
2.4.7	Optimised automation	109
2.4.8	Table top wall panels	110
2.4.9	Production of precast concrete wall panels using vertical circulation system	115
2.4.10	Control of compaction of concrete	118
2.4.11	Automation of rebar bending and wire-welded cages	118
2.5	Minimum project sizes and component efficiency for IBS	120
2.6	Design implications in construction matters	120
2.7	Conclusions	122
	References	124
3	Best Practice and Lessons Learned in IBS Design, Detailing and Construction	125
	<i>Kim S. Elliott</i>	
3.1	Increasing off-site fabrication	125
3.2	Standardisation	133
3.3	Self-compacting concrete for precast components	137
3.4	Recycled precast concrete	142
3.5	Building services	144
3.6	Conclusions	147
	References	147
4	Research and Development Towards the Optimisation of Precast Concrete Structures	149
	<i>Kim S. Elliott and Zuhairi Abd. Hamid</i>	
4.1	The research effort on precast concrete framed structures	149
4.1.1	Main themes of innovation, optimisation and implementation	149
4.1.2	Structural frame action and the role of connections	151
4.1.3	Advancement and optimisation of precast elements	156
4.1.4	Shear reduction of hcu on flexible supports	157
4.1.5	Continuity of bending moments at interior supports	159
4.1.6	Horizontal diaphragm action in hollow core floors without structural toppings	160

4.2	Precast frame connections	162
4.2.1	Background to the recent improvements in frame behaviour	162
4.2.2	Moment-rotation of beam to column connections	162
4.2.3	Research and development of precast beam-to-column connections	167
4.2.4	Column effective length factors in semi-rigid frames	170
4.3	Studies on structural integrity of precast frames and connections	170
4.3.1	Derivation of catenary tie forces	170
	References	173
Part 2	Mechanisation and Automation of the Production of Concrete Elements	177
5	Building Information Modelling (BIM) and Software for the Design and Detailing of Precast Structures	179
	<i>Thomas Leopoldseder and Susanne Schachinger</i>	
5.1	Building information modelling (BIM)	179
5.1.1	Introduction	179
5.1.2	History and ideas	180
5.1.3	Types of BIM	183
5.1.4	BIM around the world	185
5.1.5	BIM and precast structures	187
5.2	Technologies	188
5.2.1	Industry foundation classes (IFC)	188
5.2.2	IFC data file formats and data exchange technologies	192
5.2.3	BIM model software	195
5.3	BIM in precast construction	198
5.3.1	Project pricing for precast structures based on 3D models	198
5.3.2	Technical engineering	198
5.3.3	Production data and status management	202
5.3.4	Logistics, mounting, and quality management	206
5.4	Summary	207
	References	207
6	Mechanisation and Automation in Concrete Production	210
	<i>Robert Neubauer</i>	
6.1	Development of industrialization and automation in the concrete prefabrication industry	210
6.1.1	Stationary flexible forms, tables and formwork in a prefabrication plant	211
6.1.2	Long-bed production	213
6.1.3	Pallet circulation plant	217
6.1.4	CAD-CAM: the path to automation	221
6.2	CAD-CAM BIM from Industry 2.0 to 4.0	224
6.2.1	Production of non-variable parts versus production in lot size one	224

6.2.2	IBS – suitable prefabricated products for mechanization and automation	227
6.2.3	Just-in-time planning and production using ERP systems	234
6.2.4	MES systems for mechanization and automation	238
6.3	Automation methods	242
6.3.1	From simple to the highly sophisticated	243
6.3.2	Automation methods	243
6.4	Integrated and automated prefabricated production process	286
6.4.1	Structures	287
6.4.2	ERP, CAD, MES, PROD machines, HMI	289
6.4.3	HMI – integrating staff into the process	289
6.4.4	Smart factory, industry 4.0 – integration into BIM	291
6.4.5	QM included	293
6.5	Limits of automation	298
6.5.1	Labour cost versus automation	298
6.5.2	Costs, necessary skills and ROI	298
6.6	Summary and outlook	300
Part 3 Industrialisation of Concrete Structures		301
7	Lean Construction – Industrialisation of On-site Production Processes	303
	<i>Gerhard Girmscheid</i>	
7.1	Work process planning (WPP)	304
7.1.1	Construction production planning process – introduction	304
7.1.2	Construction production process – principles and sequence	310
7.1.3	Systematic basic production process planning – steps	311
7.1.4	Continuous construction process management	313
7.2	Construction production process planning procedure	314
7.3	Work process planning (WPP) – work execution estimation	322
7.4	Work process planning (WPP) – planning the processes and construction methods	329
7.5	Planning the execution process	332
7.6	Procedure for selecting construction methods and processes	336
7.6.1	Objectives when comparing construction methods	336
7.6.2	Methodological approach to comparing construction methods	338
7.7	Conclusions to Chapter 7	343
	References	344
8	Lean Construction – Industrialisation of On-site Production Processes	346
	<i>Gerhard Girmscheid</i>	
8.1	Introduction – top-down / bottom-up work planning scheduling and resource planning	347

8.2	Scheduling and resource planning	348
8.3	Site Logistics	352
8.3.1	Logistics planning	352
8.3.2	Transport logistics	354
8.3.3	Delivery, storage and turnaround logistics	355
8.3.4	Planning storage areas – storage space management	356
8.3.5	Disposal logistics	357
8.4	Weekly work plans	357
8.4.1	Lean construction – weekly work program	357
8.4.2	Equipment and material call-up	384
8.4.3	Organizing the construction workflow, construction methods, and health and safety	390
8.5	Construction site controlling process	391
8.5.1	Performance specifications	391
8.5.2	Controlling weekly work performance	393
8.6	CIP – the continuous improvement process	398
8.7	Conclusions	401
	References	403
9	New Cooperative Business Model – Industrialization of Off-Site Production	404
	<i>Julia Selberherr</i>	
9.1	Introduction	405
9.2	Objectives of the new business model	406
9.3	Modelling	408
9.3.1	Formal structuring	408
9.3.2	Contextual configuration of the outside view: development of the new service offer	409
9.3.3	Contextual configuration of the inside view: Realization of the value creation process	409
9.3.4	Overview	420
9.4	Conclusion	420
	References	421
10	Retrospective View and Future Initiatives in Industrialised Building Systems (IBS) and Modernisation, Mechanisation and Industrialisation (MMI)	424
	<i>Zuhairi Abd. Hamid, Foo Chee Hung, and Ahmad Hazim Abdul Rahim</i>	
10.1	Industrialisation of the construction industry	424
10.2	Overview on global housing prefabrication	426
10.3	Housing prefabrication in Malaysia – the industrialisation building system (IBS)	427
10.3.1	Chronology of IBS development in Malaysia	429
10.3.2	IBS roadmap	433
10.3.3	IBS adoption level in Malaysia	435
10.4	Social acceptability of IBS in relation to housing	439