



# MODERNISATION, MECHANISATION & INDUSTRIALISATION of Concrete Structures

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

**WILEY** Blackwell

# MODERNISATION, MECHANISATION AND INDUSTRIALISATION OF CONCRETE STRUCTURES

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# 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 or 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 Leopoldseder 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.

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# Contents

<i>About the Editors</i>	xi
<i>Notes on Contributors</i>	xiii
<i>Preface</i>	xvii
<b>Part 1 Modernisation of Precast Concrete Structures</b>	<b>1</b>
<b>1 Historical and Chronological Development of Precast Concrete Structures</b>	<b>3</b>
<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
<b>2 Industrial Building Systems (IBS) Project Implementation</b>	<b>61</b>
<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
<b>3</b>	<b>Best Practice and Lessons Learned in IBS Design, Detailing and Construction</b>	<b>125</b>
	<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
<b>4</b>	<b>Research and Development Towards the Optimisation of Precast Concrete Structures</b>	<b>149</b>
	<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
<b>Part 2</b>	<b>Mechanisation and Automation of the Production of Concrete Elements</b>	<b>177</b>
<b>5</b>	<b>Building Information Modelling (BIM) and Software for the Design and Detailing of Precast Structures</b>	<b>179</b>
	<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
<b>6</b>	<b>Mechanisation and Automation in Concrete Production</b>	<b>210</b>
	<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
<b>Part 3 Industrialisation of Concrete Structures</b>		<b>301</b>
<b>7</b>	<b>Lean Construction – Industrialisation of On-site Production Processes</b>	<b>303</b>
	<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
<b>8</b>	<b>Lean Construction – Industrialisation of On-site Production Processes</b>	<b>346</b>
	<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
<b>9</b>	<b>New Cooperative Business Model – Industrialization of Off-Site Production</b>	<b>404</b>
	<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
<b>10</b>	<b>Retrospective View and Future Initiatives in Industrialised Building Systems (IBS) and Modernisation, Mechanisation and Industrialisation (MMI)</b>	<b>424</b>
	<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

10.5	IBS in future – opportunity for wider IBS adoption	443
10.5.1	Greater Kuala Lumpur	444
10.5.2	Affordable housing	446
10.6	Conclusion	450
	References	450
<b>11</b>	<b>Affordable and Quality Housing Through Mechanization, Modernization and Mass Customisation</b>	<b>453</b>
	<i>Zuhairi Abd. Hamid, Foo Chee Hung, and Gan Hock Beng</i>	
11.1	Introduction	453
11.2	Design for flexibility – insight from the vernacular architecture	457
11.3	Scope of flexibility in residential housing	459
11.4	Divergent Dwelling Design (D3) – proposed mass housing system for today and tomorrow	461
11.5	Design principles of D3	464
11.5.1	The design of the unit plan	465
11.5.2	Unit configurations design	466
11.5.3	Sustainable strategies design	467
11.5.4	Structure and construction design	468
11.6	Conclusion	472
	References	473
	<i>Index</i>	475

# **Part 1**

## **Modernisation of Precast Concrete Structures**





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## Chapter 1

# Historical and Chronological Development of Precast Concrete Structures

Kim S. Elliott

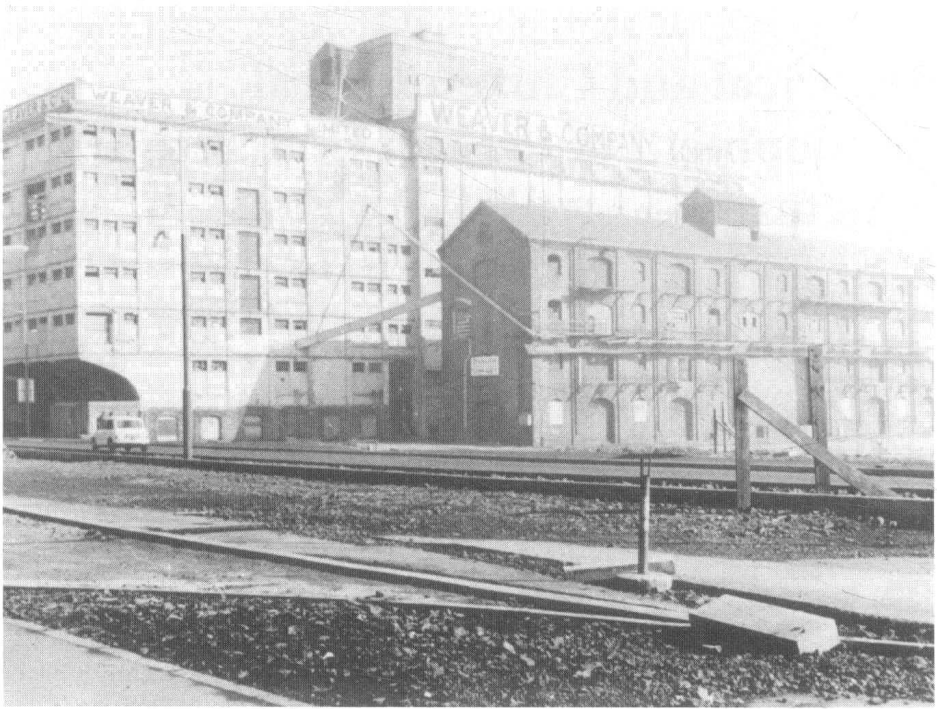
*Precast Consultant, Derbyshire, UK*

An overview of the four major phases in the twentieth-century history of precast concrete construction: developing years; mass production and standardisation; lightweight structures and longer spans; thermal mass design, shows how the beneficial issues in each period has lead to the present-day movement towards modernisation, mechanisation and industrialisation (MMI) and the interface with industrialised building systems (IBS). Timelines of market share, building height, span/depth, thermal efficiency, and hybrid and mixed precast construction are drawn through the phases from 1920 to 2010. The benefits of composite and continuous construction for prestressed concrete beams and slabs have decreased the mass of the floor construction by about 30% over the past 25 years. The conclusion shows how MMI serves and suits the demand for prefabrication of concrete-framed structures.

## 1.1 The five periods of development and optimisation

From a historical background, the prefabrication of concrete and the development of precast concrete structures for residential, commercial and industrial buildings have passed through four major periods:

1. The Developing Years (1920–1940) including the technological breakthrough of prestressed concrete (psc) and the further advancement of reinforced concrete (rc) in terms of improvements in the strength of materials, the optimisation of design and durability and resilience of the resulting elements. Figure 1.1 shows the first use of precast concrete, called *ferro-cement* at the time, in a multi-storey building.



**Figure 1.1** Weaver's Mill, Swansea. The first precast concrete skeletal frame in the United Kingdom, constructed in 1897–1898 (Courtesy Swansea City Archives).

2. The Mass Production and Standardisation Period (1945–c.1970) involved rebuilding residential post-war Europe, as well as developing south east Asia, using mainly wall panel construction (Figure 1.2), and semi-automated floor slabs such as prestressed long-line extruded or slip-formed hollow core units (hcu), eventually leading to the development of modularised “national building frames”, for example, in Figure 1.3.
3. The Lightweight and Long-span Period (1970–2000), driven by the need to produce leaner structures with greater span-to-depth ratios by using composite, continuous and integrated designs in hybrid (precast with *insitu* concrete) and mixed materials (e.g., precast with steel, timber and masonry). Figure 1.4 shows total prefabrication of a steel frame supporting prestressed hcu having a span-depth ratio of about 40, and floor area-to-structural depth ratio of nearly  $250 \text{ m}^2/\text{m}$ .
4. The Thermal Mass Period (2000 to date) responding to the demand for the sustainable and environmentally advantageous use of factory engineered concrete and off-site construction philosophies, energy storage, improving admittance of the building fabric and lowering transmittance (U-values) requirements. Figures 1.5 and 1.6 show the use of so-called “FES”, active fabric energy storage in the precast concrete elements.

There is now a new era, although some would argue this is already established in many countries, taking in the beneficial aspects of the latter day periods towards the increasingly popular trend for automated manufacture and off-site prefabrication: