

ENHANCEMENT OF CONSTRUCTABILITY CONCEPT: AN EXPERIENCE IN OFFSITE MALAYSIA CONSTRUCTION INDUSTRY

MOHD NASRUN MOHD NAWI¹, KAMARUL ANUAR MOHAMAD KAMAR¹,
MOHD RODZI ABDULLAH¹, AHMAD TARMIZI HARON¹, ANGELA LEE¹,
AND MOHAMMED ARIF¹

¹Research Institute for the Built and Human Environment,
University of Salford,
Salford, M5 4WT,
United Kingdom

Email: m.n.mohdnawi@pgr.salford.ac.uk

Abstract:

In the construction process of a traditional contracting system, most design drawings and specifications that produced by the design engineers are tend to be performance oriented, specifying an end result and materials, while leaves the means and methods for constructing the work to the contractor. While in nature, A/Es are not exactly expert in construction means and method. Consequently, the reality of construction is that most of the problems encountered in the field such as reworks, delay and low in quality or productivity are often compounded by inherent design flaws that generated in the design phase. An alternative solution to overcome the problem is by implementing of constructability concept. Constructability is often portrayed as integrating construction knowledge, resource, technology and experience into the engineering and design of a project. Since 1998, government Malaysian through Construction Industry Development Board (CIDB) seriously took an action to reform the current construction practice (currently use conventional method) towards industrialization concept. One of the main strategies had been taken by the government which introduced a concept of design of prefabrication, pre-assembly and modularization especially in public projects. This paper will highlight the initiative have be done by in the Malaysian construction industry to implement that system and indirectly the concept of constructability will be enhanced.

Keywords: Constructability, Offsite, Pre-assembly and Modularization Design, Malaysia construction industry.

INTRODUCTION

The construction industry is highly aware of the need to improve the integration, planning and control of its design and production processes. In the construction process of a traditional contracting system, most design drawings and specifications that produced by the design engineers are tend to be performance oriented, specifying an end result and materials, while leaves the means and methods for constructing the work to the contractor (Glavinich, 1995). While in nature, Architects or engineers are not exactly expert in

construction means and method (Siong, 2006). Consequently, the reality of construction is that most of the problems encountered in the field such as reworks, delay, low in quality or productivity and even legal entanglement and claims are often compounded by inherent design flaws that generated in the design phase. This inherent design flaws problem if not settled properly, it will result in major repair or replacement due to costly critical failure consequences later in the building maintenance and operation lifecycle. It is because maintenance building plays an integral role in the whole design and construction process of building (Shabha, 2003). In attempt to this problem, information and knowledge of maintenance should be shared and considered during the design process. The problem with a current practice is sometime all technical documents and records during design and construction stages are not provided to the maintenance teams (Idris, 1998 and Ramly et al. (2003). Furthermore, the level of efficiency of maintenance and communication between designs, build and maintenance teams are still low while maintainability issues are always considered late in the process. This indirectly, will effect to the future maintenance performance of project (building). Looking this situation, constructability concept is identified as one of the suitable method for the solution of fragmentation issue during the design, construction and maintenance phase. This concept allows the early involvement of professionals such as contractors and facility managers to share their knowledge and expertise in the initial stage of design in order to produce the design for ease of construction and maintenance which compliance to client needs of a construction project. However, in term of process implementation, constructability input has been hindered by the designer's partial understanding of construction requirements, diverging goals between design and construction professionals, and the resistance of the owners to formal constructability approaches because of the highly visible extra cost to projects (Arditi et al., 2002).

This paper will describes the development of techniques and strategies to support the constructability during design phase through the adoption of industrialisation (offsite) building system – IBS as a new or modern construction method. It focuses on the investigations based on the literatures based on the series of resources and industrialisation methods that have been successfully done by the Malaysian government to improve their construction performance and image since 40 years ago.

DEFINITION AND CONSTRUCTABILITY CONCEPTS

The idea or concept of constructability was come out in the late of 1970s, to integrating engineering, construction, and operation knowledge and experience to increase cost efficiency, quality and to better achieve project objectives in the construction industry. Nowadays, constructability concept has been extensively being developed and applied in the USA, UK and later in Australia, where their studies have demonstrated that improved constructability has lead to significant savings in both cost and time required for completing construction projects (Russel *et al.*, 1992a; Jergeas and Van der Put, 2001). However, in Malaysia, there a few studies have be done related to process implementation, integration and assessment of constructability concept during design phase (Nima et al. 2001; Rosli et al, 2005 and Siong, 2006).

Constructability is the optimum use of construction knowledge and experience in the conceptual planning, detail engineering, procurement, and field operations phases to achieve the overall project objectives (CII, 1986). It also identified as the integration of construction expertise into the planning and design of project (Mendelsohn, 2002). Constructability concepts have been applied in countries like the USA, the UK, and Australia (Griffith and Sidwell, 1995) and the outcome documented. For Malaysia these concepts had yet to be examined (Nima et al, 2001). Based on the constructability concepts established by the Construction Industry Institute (CII) and other relevant literature (CIRIA, 1983; Tatum, 1987; Adams, 1989; CII, 1993; CIIA, 1993; Nima *et al.*, 1999), 23 constructability concepts were formulated by Nima (2001) to utilise a study in relation to the engineered construction phases (the engineered construction process refers to the process of construction that contains the planning and design, i.e. starting from conceptual planning to the end of construction and the start-up of the project. The phases of the engineered construction process are the conceptual design, the final design, procurement, construction and start-up), as follows:

Project constructability enhancement during conceptual planning phase comprises of concepts C1 to C7:

- Concept C1: The project constructability programme should be discussed and documented within the project execution plan, through the participation of all project team members.
- Concept C2: A project team that includes representatives of the owner, engineer and contractor should be formulated and maintained to take the constructability issue into consideration from the outset of the project and through all of its phases.
- Concept C3: Individuals with current construction knowledge and experience should achieve the early project planning so that interference between design and construction can be avoided.
- Concept C4: The construction methods should be taken into consideration when choosing the type and the number of contracts required for executing the project.
- Concept C5: The master project schedule and the construction completion date should be construction-sensitive and should be assigned as early as possible.
- Concept C6: In order to accomplish the field operations easily and efficiently, major construction methods should be discussed and analysed in-depth as early as possible to direct the design according to these methods.
- Concept C7: Site layout should be studied carefully so that construction, operation and maintenance can be performed efficiently, and to avoid interference between the activities performed during these phases.

Project constructability enhancement during design and procurement phases comprises of concepts C8 to C15:

- Concept C8: Design and procurement schedules should be dictated by construction sequence. Thus, the construction schedule must be discussed and developed prior to the design development and procurement schedule.

- Concept C9: Advanced information technologies are important to any field including the construction industry. Therefore, the use of those technologies will overcome the problem of fragmentation into specialized roles in this field, and enhance constructability.
- Concept C10: Designs, through design simplification by designers and design review by qualified construction personnel, must be configured to enable efficient construction.
- Concept C11: Project elements should be standardized to an extent that will never affect the project cost negatively.
- Concept C12: The project technical specifications should be simplified and configured to achieve efficient construction without sacrificing the level or the efficiency of the project performance.
- *Concept C13*: The implementation of modularization and preassembly for project elements should be taken into consideration and studied carefully. Modularization and preassembly design should be prepared to facilitate fabrication, transportation and installation.
- Concept C14: Project design should take into consideration the accessibility of construction personnel, materials and equipment to the required position inside the site.
- Concept C15: Design should facilitate construction during adverse weather conditions. Efforts should be made to plan for the construction of the project under suitable weather conditions; otherwise, the designer must increase the project elements that could be prefabricated in workshops.

Project constructability enhancement during field operations phases (concepts C16–C23):

- Concept C16: Field tasks sequencing should be configured in order to minimize damages or rework of some project elements, minimize scaffolding needs, formwork used, or congestion of construction personnel, material and equipment.
- Concept C17: Innovation in temporary construction materials/systems, or implementing innovative ways of using available temporary construction materials/systems that have not been defined or limited by the design drawings and technical specifications will contribute positively to the enhancement of constructability.
- Concept C18: Incorporating innovation of new methods in using off-the-shelf hand tools, or modification of the available tools, or introduction of a new hand tools that reduce labour intensity, increase mobility, safety or accessibility will enhance constructability at the construction phase.
- Concept C19: Introduction of innovative methods for using the available equipment or modification of the available equipment to increase their productivity will lead to a better constructability.
- Concept C20: In order to increase the productivity, reduce the need for scaffolding, or improve the project constructability under adverse weather conditions, constructors should be encouraged to use any optional preassembly.
- Concept C21: Constructability will be enhanced by encouraging the constructor to carry out innovation of temporary facilities.

- Concept C22: Good contractors, based on quality and time, should be documented, so that contracts for future construction works would not be awarded based on low bids only, but by considering other project attributes, i.e. quality and time.
- Concept C23: Evaluation, documentation and feedback of the issues of the constructability concepts should be maintained throughout the project to be used in later projects as lessons learned.

OFFSITE AND CONSTRUCTABILITY

The fundamental idea of offsite is to move some effort away from the construction site to more controlled environment of the manufacturing floor. Offsite is defined as the manufacture and pre-assembly of components, elements or modules before installation into their final location (Goodier & Gibb, 2007). Offsite construction, in addition, is refer to that part of the construction process that is carried out away from the building site, such as in factory or sometimes in specially created temporary production facilities close to the construction site (Gibb & Pendlebury, 2005). The offsite benefits extolled from the specific issues in construction sector such as improvement in quality, cost and time certainty (Pan et al, 2005) to more generic benefits like customer satisfaction and environment (Treadway, 2006).

Although, the improvement of constructability is rarely been mention as the benefit of offsite but in theory, offsite can improve constructability by providing designers with the fresh perspective and outlook on the concept of repetition, preassembly and standardization (as stated above in the contractibility's concept - Concept C13). For a long time, repetition, and standardisation is bemoan of dull and unattractive design but re-branding effort of offsite recently give a different view in the concept of sensible design where optimisation can go along with trend and awareness on sustainability issue. More important, standardisation allows easier assembly of components with the opportunity for exchange or addition modules thus make sense in term of cost reduction especially in mass-production process (Buildoffsite, 2008). The introduction of modular coordination concept to design offsite components, will improve overall constructability in construction project. Modular coordination is a concept of coordination of dimension and spaces where building and components are dimensioned and positioned in a basic unit or module known as 1 M which equivalent to 100 mm (Hamid et al, 2008). Although modular coordination can be used to design conventional system but it is most associated with offsite and manufactured production components where the element of repetitiveness exists.

However, in order to reap the maximum benefit of offsite, one has to synchronize three major function; construction, manufacturing and design. Perhaps, the plausible solution of adopting of offsite principal to improve construction constructability would face several shortcomings particularly on the design integration issues as depicted in the followings:

- Traditional contracts practice brings the constructors into the project only after the design has been substantially completed and the specification has been developed. No proper channel for constructability input or critiques to improve in design. Constructability input is needed due to high complexity of offsite project
- Offsite and late design change does not work together. Later design change cannot readily be implemented without influencing the production schedule and extending of time which are the pitfall for every project (NAO, 2005). It is vital to involve designer, supplier, manufacture, architect and client to ensure the development is designed for manufacture and the design suit to manufacture capability and site condition (ibid)
- The concept of design integration is still new in construction. The nature of construction industry is competitive and fragmented where the genuine collaboration is rare due to the issue of trust
- There is still lack of designers and professionals trained in offsite and prepared with an offsite skill set to understand the complex harmonisation between offsite design and constructability. The designer has to choose between the designs that could be build with widely available systems in the market or producing specialised design in offsite that will allows aesthetic attribute

There is consensus of opinion that to harmonising design and manufacturing capacity lies on the need for early involvement between the design team, manufacturer, contractors and clients (Pan et al, 2008; Sanderson, 2003; Blismas, 2007 and Gibb, 2001). It was commented that offsite need to be integrated from the start of the design process so that the whole design and construction process to be aligned (Goodier and Gibb, 2007). This will eventually lead to a call for better coordination and design integration between all parties involve in offsite construction project (NAO, 2005). The project team needs to be assembled at the beginning of each offsite project to discuss on manufacture capability and constructability in an open collaboration environment. Designers need to have valuable input and critique on the issues of constructability particularly in offsite where the late design change is not a viable option to the project team. There is imperative for the clients to play the role of coordinator to make this thing happen.

To achieve design integration during the project implementation, offsite construction team requires real time information between the factory and the project site (Malik, 2006). Information and Communication Technology (ICT) can be a vital and reliable tool to offsite implementation and to integrate design in offsite project. Extensive ICT will support tool effectively handles updates change (Lessing, 2005), support integration of design (Oostra & Johnson, 2007) and source for accurate information (Lessing, 2006). An example of ICT implementation in IBS project is a research carried out by Kaner et al. (2008) on projects which using Building Information Modelling (BIM) as a tool. The research was conducted on medium sized structural engineering firms which had different introductions to BIM. An important result of the research however shows that, in the context of constructability, there were no drawing errors that led to the construction problems on site, and all pieces built in accordance with the shop drawings, fit the complex curved geometry of the structure.

On the other hand, based on the research conducted by Ting et al. (2007), the result showed that BIM enables the users to visualize the constructability of the proposed construction approach by implementing 4D modelling. The system also assists the project team to design a precise construction schedule so as to remove any potential unproductive activities. The result of the study is similar to the result from a research by Koo and Fischer (2000). In the study, the 4D models able to identify and eliminate the construction related problems before going to site. It further investigated whether 4D could help project participants identify problems that would normally be overlooked in traditional bar chart techniques. The work concluded that 4D models communicate a schedule more clearly and enable even relatively inexperienced construction professionals to identify problems. The identification of problems before materialising could help companies save time and money in the long term. In developing 4D modelling, according to Kymmel (2008), the construction schedule can be developed if a preliminary schedule is available and a schematic construction sequence can be simulated. The 4D modelling could facilitate the visualization of the construction process and allow the consideration of alternative approaches to sequencing, site layout, crane placement, etc., during construction process. Eastman et al. (2008) then further explain that this graphic simulation provides considerable insight into how the building will be constructed day-by-day and reveals source of potential problems and opportunities for possible improvements which agreed with the case study conducted by Ting et al. (2007) and Koo and Fischer (2000). Hence, it is good tool for effective production which error of design and incapability of manufacture to produce certain design can be addressed efficiently (ibid).

MALAYSIAN GOVERNMENT'S INITIATIVE FOR IBS (OR OFFSITE) ENHANCEMENT PROGRAMS

In Malaysia, the term Industrialised Building System (IBS) is widely used by the government and practitioners to represent offsite construction. IBS is a construction technique in which components are manufactured in a controlled environment (on or off site), transported, positioned and assembled into a structure with minimal additional site works (CIDB, 2003a). The term also covered the concept of Modular Coordination (MC) and Open Building System (OBS) (CIDB, 2003a).

IBS has been introduced in Malaysia since the 60's by the use of pre-cast concrete beam-column element and panelised system (CIDB, 2003a; Thanoon et al., 2003). The projects in Jalan Pekeliling, Kuala Lumpur and Rifle Range, Penang had used Danish System and French Estoit System respectively. However due to some criteria that were not suitable for local cultural habits, the technology did not take off as planned. The recent influx of foreign workers in the 90's, however, has reignited the interest on IBS. IBS research and promotion was pioneered by Housing Research Centre (HRC), Universiti Putra Malaysia. HRC had organised a series of national and international colloquiums and seminars on IBS. In 2001, their research on *'Interlocking load bearing hollow-block building'* namely the 'Putra Block' has won the prestigious 'Geneva Gold Medal' award for innovation. HRC were also engaged with the National Affordable Housing research program with the

Ministry of Housing and Local Government in 2001. In 1999, Construction Industry Development Board (CIDB) Malaysia formed the IBS Steering Committee in the effort to bring to the fore all the IBS related issues in a framework and IBS Strategic Plan 1999 were published. In 2003, the government, through CIDB published 'parliament endorsed' roadmap to guide the practitioners and decision makers in adopting IBS in Malaysia. Known as the Industrialised Building Systems (IBS) Roadmap 2003-2010, the master plan is based on the 5-M Strategy (Manpower, Materials-Components- Machines, Management-Processes-Methods, Monetary and Marketing) with the target of having an industrialised construction industry and introduce open building concept by the year 2010 (CIDB, 2003a). The initiative of roadmap implementation is currently lead by two working groups; IBS Steering Committee and IBS Technical Committee. CIDB's IBS Center has taking a role of secretariat to monitor all the activities.

Even though IBS has been introduced for over 40 years, the government of Malaysia still feels that the pace of implementation and usage of IBS is still slow. However, in the last couple of years, the momentum has steadily increased and has gradually become part of the industry. Many private companies in Malaysia have teamed up with foreign experts from Australia, Netherlands, United State and Japan to offer pre-cast solution to their project (CIDB, 2003b). There have a number of IBS key projects such as:

- 17 storeys flats along Jalan Pekeliling, Kuala Lumpur project that was awarded to Gammon/ Larsen Nielsen using a Danish System of large panel of pre-fabricated system (CIDB, 2003b)
- Housing project comprising 6 blocks of 17 storeys flat and 3 blocks of 18 storeys flat was constructed at Jalan Rifle Range, Penang. The project was awarded to Hochtief/ Chee Seng using the French Estoit System (Din, 1984)
- Taman Tun Sardon Housing project in Penang. An IBS pre-cast component and system was used in the project and was designed by the British Research Establishment (BRE) in 1978 for low cost housing in tropical countries.
- Perbadanan Kemajuan Negeri Selangor (PKNS), low cost houses and high cost bungalows project in Selangor (CIDB, 2003b). The project is under a state government development agency which acquired pre-cast concrete technology from Praton Haus International based in Germany
- The 36-storeys Dayabumi complex which the first project used steel structure (part of IBS) as a method of construction was completed in 1984 by Takenaka Corporation of Japan (CIDB, 2003b)
- Hybrid construction (mixed used of IBS and conventional method) for national scale infrastructure projects and national landmark such as Bukit Jalil National Sport Complex (1998), Kuala Lumpur City Centre (KLCC) (1998), Light Rapid Transit (LRT) (1997), Kuala Lumpur International Airport (KLIA) (1997) and School Teacher's Quarters (2001)

The following is the key events of IBS promotion and initiatives taken by the government: in Malaysia:

- Through the *National Yearly Budget* announcement back in September 2004, the government had pledged to construct 100,000 units of affordable houses using IBS. In addition, all new government building projects were required to have at

least 50% IBS content which had been calculated through the IBS Score Manual developed by CIDB.

- The Construction Industry Master Plan 2006-2015 (CIMP 2006-2015) had been published in December 2006 as means to chart the future direction of the Malaysian construction industry. The effort to promote IBS is highlighted under Strategic Thrust 5: Innovate through R&D to adopt a new construction method.
- Beginning from 2007 onwards, new incentives for IBS adopter has been introduced. The exemption of the levy (CIDB levy - 0.125 % of total cost of the project according to Article 520) on contractors that used some kind of IBS in 50% of the building components has been commenced since 1st January 2007 (Hamid et al, 2008).
- In early 2007, IBS Centre had been established in Cheras to promote IBS in Malaysia and also to play the role of consultant. The centre is equipped with IBS showhouse and Research and Development (R&D) capacity. Construction Research Institute of Malaysia (CREAM) was initiated to manage IBS research.
- The new circular of by the Ministry of Finance dated on October 2008 had emphasized on the full utilization of IBS for government's projects in Malaysia. Among the pressing matters raised in the circular were the use of IBS component in government projects must not be less than 70% and the inclusion of IBS component as part of contract documents for all building works. As in February 2009, 320 government projects worth RM 9.43 billion had been carried out using the IBS technology

CONCLUSION

Although, the introduction of IBS (or offsite) construction faced the same problem to adopt constructability as for conventional method, the systems can provide practitioner with the fresh outlook on this issues. As stated by previous researchers, IBS (or offsite) adoption can be a great platform to improve constructability in the sense of design for standardization, preassembly and repetitiveness. More government incentive, research and promotion to generate greater use of IBS (or offsite), may solve the issue of constructability's implementation which indirectly could become good drivers or strategies for the process of enhancement of constructability. Initiatives have be taken by the Malaysian government to implement IBS (or offsite) seriously, was looked as a good step in order to improve the level of constructability in the construction business industry. In the end, constructability concept is believed could be an effective approach in order to enhance the level of product/project design by the integration of construction expertise into the planning and design of project.

FUTURE RESEARCH

Future research on Offsite construction and the issue of constructability:

- To capture and document the best practices in constructability and develop a model for transfer of technology and benchmarking in order gain improvement in practices
- To identify stakeholder's role and responsibility in offsite project particularly into the issue of constructability
- To further investigate the process of design integration in project particularly in offsite construction project
- To develop a model to gain input and critique on constructability at the beginning of the construction project. The model maybe in the form of checklist, contract or list of best practices
- To develop a format for client project briefing at the beginning of offsite project to include the issue of constructability and manufacture capability in there
- To develop a training syllabus for designers and engineer which will focus on the issues of constructability in offsite construction
- To develop a framework for collaborative relationship among professional players in the early stage of construction project.

REFERENCE

- Adams, S., *Practical Buildability*, Construction Industry Research Information Association, Butterworths, London, 1989.
- Ahmad B. R., *The Link Between Design and Maintenance. Proceeding: Seminar on Building maintenance – Towards A Building Caring Society*, Ministry of Housing and Local Government, Triple Zek HR & Humohdin Consult. Kuala Lumpur. pp. S2/21-42, 2003.
- Arditi, D., Elhassan, A., and Toklu, Y. C., *Constructability Analysis in the Design Firm*. Journal of Construction Engineering and Management. 128(2): 117-126, 2002.
- Blismas, N. Off-site manufacture in Australia: *Current state and future directions Cooperative Research Centre for Construction Innovation*, Brisbane, Qld, Australia, pp. 1-37, 2007.
- Buildoffsite, *Your guide to specifying Modular Buildings Maximising value and minimising risk*, Buildoffsite & BAA, London, 2008.
- CII, *Constructability: A Primer*, Publication 3-1, Construction Industry Institute, Austin, TX., 1986.
- CII, *Constructability Implementation Guide*, Special Publication 34-1, Construction Industry Institute, Austin, TX, 1993.

- CIIA, *Constructability Principles File*, Construction Industry Institute Australia, University of South Australia, Adelaide, 1993.
- Construction Industry Development Board (CIDB), *Industrialised Building Systems (IBS) Roadmap 2003-2010*, CIDB Malaysia, Kuala Lumpur, 2003a.
- Construction Industry Development Board (CIDB), *National IBS Survey 2003*, CIDB Malaysia, Kuala Lumpur, 2003b.
- CIRIA *Buildability: An Assessment*, Special Publication 26, Construction Industry Research Information Association, Ascot, 1983.
- Din, H., *Industrialised building and its application in Malaysia*. Seminar on Prefabrication of Building Construction, 1984.
- Eastman C., Teicholz P., Sacks R., and Liston K., *BIM Handbook : A Guide to Building Information Modelling for Owner, Managers, Designers, Engineers, and Contractor*, John Wiley and Sons, Inc. New Jersey, 2008.
- Ghasan Shabha, *A low-cost maintenance approach to high-rise flats*, Journal of Facilities, 21, 313-322, 2003.
- Gibb, A. G. F., *Standardization and Pre-assembly – Distinguishing Myth from Reality using Case Study Research*, Construction Management and Economics, 19, 307–315, 2001.
- Gibb, A. and Pendlebury, *Buildoffsite Glossary of Term*, Buildoffsite UK, London, 2005.
- Glavinich, T. E., *Improving Constructability during Design Phase*. Journal of Architectural Engineering. 1(2): 73-76, 1995.
- Goodier, C. and Gibb, A., *Future opportunities for offsite in the UK*, Construction Management and Economics, 25 (6), 585 — 595, 2007.
- Goodier, C. and Gibb, A., *Buildoffsite: Glossary of Term*, DTI and Buildoffsite, London, 2006.
- Griffiths, A., and Sidwell, A. C., *Constructability in Building and Engineering Projects*, Macmillan, London, 1995.
- Hamid, Z. A., Kamar, K. A. M., Zain, M. Z. M., Ghani, M. K. and Rahim, A. H. A., *Industrialised Building System (IBS) in Malaysia: The Current State and R&D Initiatives*, Malaysian Construction Research Journal (MCRJ), 2 (1), 1-11, 2008.

- Idris, M.M., *Assessment of the factors influencing the maintenance programme of a large university building in Riyadh*, Construction Management and Economics, Vol. 16 No.6, pp.673-9, 1998.
- Jergeas, G., and Van der Put, J., *Benefits of Constructability on Construction Projects*, Journal of Construction Engineering and Management. 127(4): 281– 290, 2001.
- Kaner, I., Sacks, R., Kassian, W., and Quitt, T., *Case Studies of BIM Adoption for Precast Concrete Design by Mid-Sized Structural Engineering Firms*, ITcon Vol. 13, pg. 303, 2008.
- Koo B. and Fischer M., *Feasibility study of 4D in commercial construction*, Journal of Construction Engineering and Management pg. 251– 260, July–August, 2000.
- Kymmel W., *Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations*, The Mc-Graw Hill Companies, 2008.
- Lessing, J., Stehn, L. and Ekholm, A., *Industrialised Housing: Definition and Categorization of the Concept*, Proceedings IGLC-13 Sydney, Australia, 2005.
- Lessing, J., *Industrialised House-Building - Concept and Processes*, PhD Thesis Department of Construction Sciences Lund Institute of Technology, Sweden, 2006.
- Malik, N. A. F., *Supply Chain Management in IBS Industry*, Malaysian International IBS Exhibition (MIIE), Construction Industry Development Board (CIDB) Malaysia, 2006.
- Mendelsohn, R., *The constructability review process: A constructor's perspective*, J. Manage. Eng., 13(3), 17–19, 1997.
- NAO, *Using modern methods of construction to build homes more quickly and efficiently*, National Audit Office, London November 2005
- Nima, M. A., *Constructability factors in the Malaysian construction industry*, Ph.D. thesis, University PutraMalaysia, Selangor, 2001.
- Nima, M. A., Abdul-Kadir M. R. and Jaafar, M. S., *Evaluation of the engineer's personnel's role in enhancing project constructability*, Facilities, MCB University, 17(11), 423–30, 1999.
- Oostra, M. and Claeson-Jonsson, C., *Best Practices: Lesson Learned on Building Concept In Open Building Manufacturing- Core Concept and Industrial Requirement* (Eds, Kazi, A. S., Hannus, M., Boudjabeur, S. and Malone, A.) VTT Finland and Manubuild Consortium, pp. 15, 2007.

Pan, W., Gibb, A. G. F. and Dainty, A. R. J., *Offsite Modern Methods of Construction, Housebuilding Perspectives and Practices of Leading UK*, 2005.

Housebuilders, *Buildoffsite Report*, Loughborough University, pp. 14, 2005

Pan, W., Gibb, , F., A. G. and Dainty, A. R. J., *Leading UK Housebuilders' Utilization of Offsite Construction Methods*, Building Research & Information, 36 (1), 56 — 67, 2008.

Russell, J., Gugel, J., and Radke, M. W., *Benefits of Constructability: Four Case Studies*, The Construction Industry Institute, Austin, Texas, 1992a.

Rosli Mohamad Zin. *Constructability Assessment of Project at Design Phase*. Faculty of Civil Engineering, Universiti Teknologi Malaysia: PhD. Thesis. Unpublished, 2004.

Sanderson, G., *A strategic review of the use of modern methods of construction in new-build and refurbishment housing projects*, Richard Hodgkinson Consultancy, October 2003

Tatum, C. B., *Improving constructability during conceptual planning*, Journal of Construction Engineering and Management ASCE, **113**(2), 191–207, 1987.

Treadaway, K., *Modern Methods of Construction: the current position -SCRI Forum*, The Salford Centre for Research & Innovation (SCRI), Salford, 2006.

Ting H. A., Kong C. W., Guo H.L, Baldwin A., and Li H., *A virtual prototyping system for simulating construction processes*, Automation in Construction 16 576–585, 2007.

W.A.M. Thanoon, Lee Wah Peng, M.R.A. Kadir, Mohd Salleh Jaafar & Mohd Sapuan Salit, *The Essential Characteristics of Industrialised building system*, International Conference Industrialised building systems, Kuala Lumpur, Malaysia, 2003.

Woon Kai Siong, *Integrating Construction into the Design Process*, Unpublished Thesis, University of Technology Malaysia, 2006.