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The Hong Kong Polytechnic University

Department of Building and Real Estate

Rethinking Construction Project Management Using the VP-based Manufacturing Management Model

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A thesis submitted in partial fulfillment of the requirements
for the Degree of Doctor of Philosophy

October 2008

CERTIFICATE OF ORIGINALITY

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ABSTRACT

Manufacturing companies have made many significant improvements in both productivity and management efficiency over the last century. This progress, however, has not been matched in the construction industry, which is still beset with a variety of long standing problems including time and schedule overruns, poor health and safety conditions as well as low quality and productivity. Learning from the manufacturing industry is a useful approach to improving the productivity of the construction industry and to solving problems arising from construction processes. Construction industry researchers and practitioners are increasingly seeking to apply the experience accumulated in the manufacturing industry and, to-date, some new management concepts have been adopted in the construction industry.

In this research, through the use of Virtual Prototyping (VP) technology, the IKEA model as a representative of the manufacturing industry is studied and implemented in construction project management (CPMa). The IKEA model is first analysed and then it is proposed how the IKEA model is applied to optimize design and construction processes and simplify management activities. A case study is also presented to demonstrate the improvement of construction project management through using the VP-based IKEA approach. The details of these are described as follows.

A literature review clarifies the definition of construction project management,

analyses the limitations of traditional CPMa methods, and introduces and comments on some innovative CPMa methods. Additionally, as an important information technology (IT) support tool to this research, VP technology arising from the manufacturing industry is reviewed. This makes the focus of this research clear and provides a great deal of experience for this study.

As a typical representative of the manufacturing industry, the IKEA Group is selected and analysed and the IKEA model is proposed. The model’s feasibility for the construction industry is discussed using the questionnaire method and comparison analysis method. The key technique for using the IKEA model in the construction industry, i.e. VP technology, is customized.

The VP-based IKEA model, then, is applied to construction project management (i.e. cast-in-situ construction and precast construction). Cast-in-situ construction is a traditional construction method is widely used. However, time and cost overruns and quality problems often occur, to the extent that these problems have been regarded as normal features for all construction projects. This leads to the low productivity of the construction industry. The aim of using the VP-based IKEA model to cast-in-situ construction projects is to change this situation in two ways, i.e. the optimization of construction processes and the simplification of management activities.

Precast construction, on the other hand, is different from conventional cast-in-situ

construction. In theory it has many advantages (e.g. rapid construction, high quality), however these are seldom achieved in real-life construction projects. In order to make precast construction more effective, the IKEA model is applied to precast construction management via the combination of VP technology. The application of the VP-based IKEA model to precast construction mainly focuses on design-production-transportation optimization and assembly optimization.

Based on the application of the VP-based IKEA model in construction project management, two real-life construction projects in Hong Kong are studied to demonstrate the feasibility and effectiveness of the IKEA model in, respectively, cast-in-situ construction and precast construction. It is shown that the VP-based IKEA model can improve construction project management by reducing construction time and cost, improving construction safety and quality, especially for precast construction. Finally, the conclusions of this research are drawn and some suggestions for future research are presented.

PUBLICATIONS ARISING FROM THE PHD STUDY

Refereed Journal Papers

1. Li, H., Guo, H.L., Skibniewski, M.J. and Skitmore, M. (2008). Using the IKEA model and Virtual Prototyping technology to improve construction process management. *Construction Management and Economics*, 26(9), 991-1000.

2. Guo, H.L., Li, H. and Skitmore, M. (2009). Life cycle management of construction projects based on Virtual Prototyping technology. *Journal of Management in Engineering*, ASCE, accepted for publication.

3. Li, Y., Guo, H.L., Li, H., Wang, Y.W. and Wang, Z.R. (2009). Information systems-based real estate macro-control systems. *International Real Estate Review*, in printing.

4. Li, H., Guo, H.L., Huang, T., Chan, K.Y.N. Chan, G. and Skitmore, M. (2009). Rethinking precast construction management using the VP-based IKEA model. *Journal of Construction Engineering and Management*, ASCE, under review.

5. Li, H., Guo, H.L., Kong, S.C.W. and Chen, Z. (2009). Optimization of curved roof surface design using GA. *Journal of Engineering, Design and Technology*, under review.

6. Huang, T., Kong, C.W., Guo, H.L., Baldwin, A. and Li, H. (2007). A virtual prototyping system for simulating construction processes. *Automation in Construction*, 16(5), 576-585.

7. Li, H., Huang, T., Kong, C.W., Guo, H.L., Baldwin, A., Chan, N. and Wong, J. (2008). Integrating design and construction through virtual prototyping. *Automation in Construction*, 17(8), 915-922.

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1. Guo, H.L., Li, H., Li, Y. and Huang, T. (2008). Life cycle management of construction projects based on virtual prototyping technology. A paper published in *Proceedings of ICCCBE-XII & INCITE 2008* (pp. 137), 16th-18th October, 2008, Beijing, China.

2. Huang, T., Li, H. and Guo, H.L. (2008). A survey on construction virtual prototyping approach. A paper published in *Proceedings of ICCCBE-XII & INCITE 2008* (pp. 301), 16th-18th October, 2008, Beijing, China.

3. Huang, T., Kong, C.W., Guo, H.L., Wong, J., Baldwin, A. and Li, H. (2006). Virtual prototyping of construction processes. A paper published in *Proceedings of the World IT Conference for Design and Construction, INCITE/ITCSED 2006 on "IT Solutions for the Design & Management of Infrastructure Construction Projects"* (pp. 365-378), 15th-17th, November, 2006, New Delhi, India.

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my supervisor Professor Heng LI at that time when this thesis was finished. He is a warm-hearting man with profound knowledge. During the course of my PhD study, he gives me a great support to my study and life and inspires me with the achievement of my PhD study. I thank him very much for his continuous encouragement and selfless help to me.

I am full of gratitude to Professor Yaowu WANG and Professor Xiaodong LI at Harbin Institute of Technology for their care and encouragement to me. This makes me confident in my study.

I would like to deep thank Professor Qiping SHEN and Professor Liyin SHEN at The Hong Kong Polytechnic University, Professor M.M. KUMARASWAMY at The University of Hong Kong, Professor Ming SUN at University of the West of England, Professor Martin SKITMORE at Queensland University of Technology for their kind help and useful suggestions for my research, which help to the completion of this thesis.

I am thankful to the personnel of China Overseas Holdings Ltd and Gammon Construction Ltd, especially Mr. Yaping LIU, Mr. Ruisheng GONG, and Mr. Haoran WANG, for their help to this study. Some real-life cases are provided and

questionnaire investigation is conducted selflessly by them. This makes this thesis be finished on time.

Moreover, I would like to acknowledge my friends and colleagues in the Department of Building and Real Estate of The Hong Kong Polytechnic University. Although it is too much to list all of them here I really thank them all for their kind help and care to me. They make me a happy life and study in the strange land.

I also give my special thanks to the Construction Virtual Prototyping Lab (CVPL) and my friends in the lab. CVPL is a nice and creative lab and offers me a good research environment. Most of my inspirations for my research are gotten there. My colleagues there also give me kind cares and selfless helps. They are Mr. Ting HUANG, Mr. Stephen KONG, Mr. Neo CHAN, Mr. Greg CHAN, and Mr. Jack CHUNG.

In the end, I cannot almost get a word to express my appreciation to my wife, parents, parents-in-law, sisters, and brothers for their understanding, selfless support and love to me. Without these I would not achieve my PhD study. I just want to say to them: “Thank you and I love you so much!”

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LIST OF ABBREBIATIONS

2D	Two-dimensional
3D	Three-dimensional
4D	Four-dimensional (3D plus time)
ABC	Activity-based Construction
ACBM	Activity Cycle-based Modelling
ACD	Activity Cycle Diagrams
A/E	Architectural/Engineering
AI	Artificial Intelligent
AS	Activity Scanning
ASD	Architectural Services Department
BIM	Building Information Modelling
BS	Building Services
CAD	Computer Aided Design
CM	Construction Management
CMM	Construction Method Modeler
CPM	Critical Path Method
CPMa	Construction Project Management
CRISP	Construction Research and innovation Strategy Panel
CVPL	Construction Virtual Prototyping Lab
D-B	Design-build

D-B-B	Design-bid-build
DES	Discrete Event Simulation
DFM	Design for Manufacturability
DFL	Design for Logistics
FE	Further Education
GA	Genetic Algorithms
HDB	Housing Development Board
IT	Information Technology
IVE	Immersive Virtual Environment
JIT	Just-in-time
KM	Knowledge Management
LC	Lean Construction
LM	Lean Manufacturing
LOB	Line-of-balance
LP	Lean Production
MAXEST	Maximal Early Start Time
MINTF	Minimal Total Float
MINLFT	Minimal Late-finish Time
MMM	Manufacturing Management Model
ND	N-dimensional
PERT	Program Evaluation and Review Technique
PSBRC	Pre-emptive Scheduling under Break and Resource-constraints

PSO	Particle Swarm Optimization
QCE	Quality Control Engineer
QS	Quantity Surveyor
RCPS	Resource-constrained Project Scheduling
RCPSB	Resource-constrained Project Scheduling Pproblem
RISim	Resource-interacted Simulation
S3	Stochastic Simulation-based Scheduling System
SCM	Supply Chain Management
SO	Safety Officer
TKO	Tseung Kwan O
TPS	Toyota Production System
TQM	Total Quality Management
VCE	Virtual Construction Environment
VDC	Virtual Design and Construction
VFP	Virtual Facility Prototyping
VP	Virtual Prototyping
VR	Virtual Reality
WC	Work Content

CHAPTER 1 INTRODUCTION

Construction project management (abbreviated here as CPMa to distinguish it from critical path method, i.e. CPM) has a direct influence on the productivity of the construction industry. Its innovation is studied in this PhD thesis to improve the productivity of the industry. This chapter describes the background of the research, presents its scope and objectives, builds the logic of the research, proposes a research methodology, analyses the significance of the research, and finally offers the structure of the thesis.

1.1 Background of the Research

In the United States, the productivity of the construction industry has steadily declined over past 40 years, while that of other industries (e.g. the manufacturing industry) has improved dramatically over the same time period (see Figure 1.1) (Teicholz, 2004). Over the past decade, this trend has slightly improved but the decline in construction labour productivity relative to the rest of the industry has continued. Similar to the US, the decline in construction productivity has happened in other countries e.g. Japan (see Table 1.1). This means that over the past decades, the construction industry has required more work hours for the same output compared to other industries. Why has this happened?

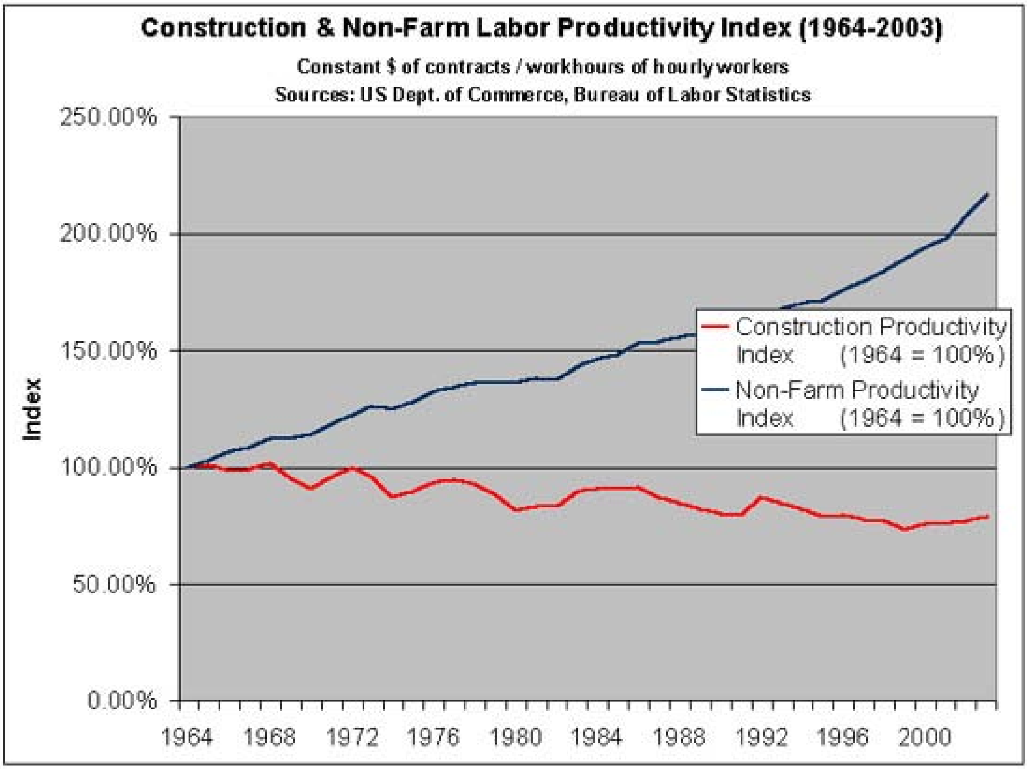
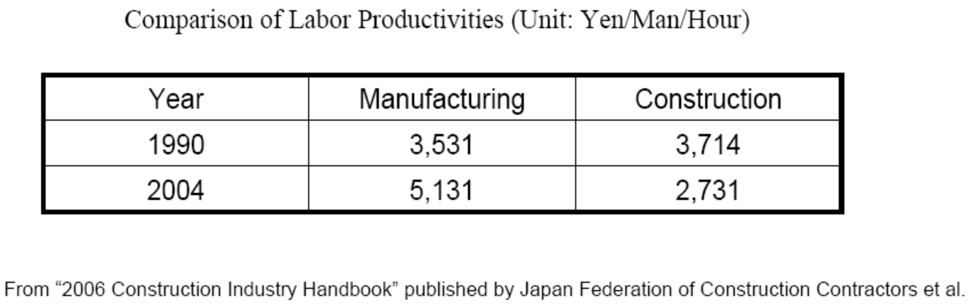


Figure 1.1 Labour productivity index for US construction industry and all non-farm industries from 1964 to 2003

Table 1.1 Labour productivity for Japan construction industry and manufacturing industry in 1990 and 2004



Comparison of Labor Productivities (Unit: Yen/Man/Hour)

Year	Manufacturing	Construction
1990	3,531	3,714
2004	5,131	2,731

From “2006 Construction Industry Handbook” published by Japan Federation of Construction Contractors et al.

Some of the productivity improvements in other industries have been attributed to the utilization of information technology (IT) and a reengineering of processes (Drucker, 2006). Fox example, lean manufacturing processes have significantly influenced the automobile industry and made some of companies improve at least two times (Womack et al., 2006). Although some of information technologies have been employed in the construction industry, for example CAD (Computer Aided Design), project planning tools, Web-based collaboration tools, etc., the industry's productivity continues to decline. The main reason identified for this is the continued use of conventional construction project management approaches. At the same time, although some innovative management methods are developed, they are not successfully and extensively adopted in the construction industry.

Conventional construction project management leads to a high rework cost (see Figure 1.2) owing to design errors or an inappropriate construction plan, which results in time or material waste. Rework has been identified as the primary factor that contributes to time and cost overruns in many construction projects (Abdul-Rahman, 1995; CII, 1989; Love, 2002). Delays and cost overruns are seemingly the rule rather than the exception in the construction industry (CIDA, 1993). Projects often appear to be going smoothly until near the end when errors made earlier are discovered, necessitating costly rework (Cooper, 1993; Eden et al., 2000; Love, 2002).

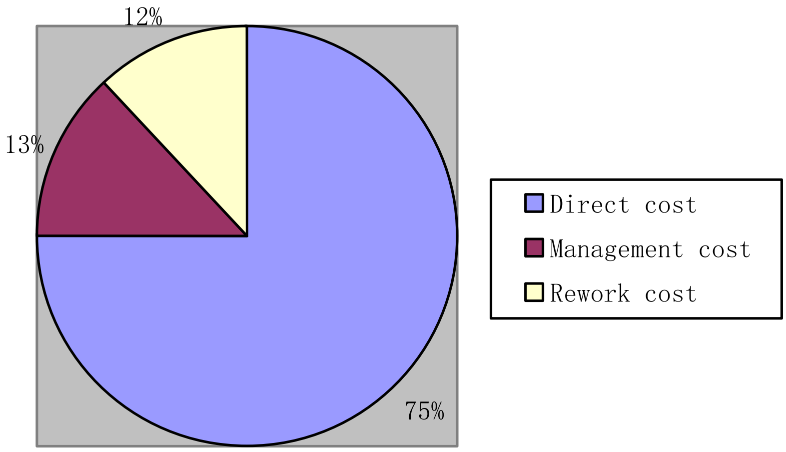


Figure 1.2 Distribution of construction cost

At the same time, the management process and management team is very redundant and this makes management cost high (see Figure 1.2). Figure 1.3 shows the sketch map of a construction site, which involves a "super" management team. It focuses only on the management of what happened, that is, so-called passive management. Due to the increased complexity of buildings, for example in super-high-rise buildings and non-typical structures, more and more problems occur. More managers are needed to deal with these problems and as a result an enormous management team appears. This leads to high management costs and low productivity.

Figure 1.3 The sketch map of a construction site

In order to improve the productivity of the construction industry, this research makes an effort to introduce a production and management model of the manufacturing industry to the construction industry to optimize construction processes and simplify management activities.

1.2 Scope of the Research

Construction projects involve many parties (e.g. owners, consultants, designers and contractors) and various phases (e.g. conception, planning, design and construction), from which the scope of construction project management is different. This research mainly focuses on construction management (CM) from the point of view of designers and contractors, i.e. planning/design and construction process management (see Figure 1.4).

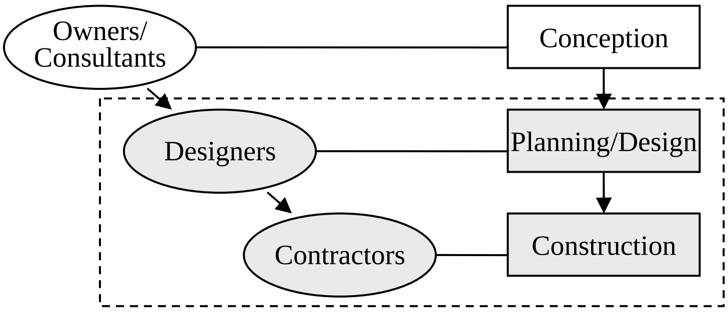


Figure 1.4 Scope of construction management delimited in the research

Construction industry researchers and practitioners are increasingly seeking to apply the experience accumulated in the manufacturing industry (Bresnen and Marshall, 2001) and, to date, some management concepts have been adopted. For example, total quality management (TQM), supply chain management (SCM) and lean manufacturing (LM) (e.g. Wong and Fung, 1999; Green, 1998; Lapinski et al., 2007) are now familiar management concepts in the construction industry. Although these concepts are not widely employed in the construction industry, this provides experience and reference for this research.

Of particular interest has been the development of lean construction concepts arising out of Koskela’s (1992) challenge to the traditional time-cost-quality trade-off paradigm and elaborated by Ballard and Howell (1994a, 1994b) as “a way to design production systems to minimize waste of materials, time, and effort” (Koskela and Howell, 2002). This research follows that tradition in presenting a construction project management innovation based on a combination of the IKEA Group approach (termed here the IKEA model) and Virtual Prototyping (VP) technology. Note that the IKEA model here is a typical manufacturing management model (MMM) and therefore it is adopted to conduct the study.

1.3 Research Objectives

The general objective of the research is to propose an effective and efficient construction project management approach and improve the productivity of the construction industry through the application of the manufacturing management model to construction projects based on VP technology. Specifically the objectives of the research are as follows:

1) To identify and elaborate on the roots of the low productivity occurring in the global construction industry;
2) To discuss the success factors of the manufacturing management model and the possibility of applying it to the construction industry to improve its productivity;
3) To propose the implementation approach of the manufacturing management model to the construction industry;
4) To extend the application of information technology to the construction industry and reform the traditional management method of the industry;
5) To improve design and construction processes and simplify construction management activities; and
6) To reduce time and cost overruns, ensure construction quality and safety and the protection of the environment.

1.4 Logic of the Research

This research follows the logic framework shown in Figure 1.5. The author first identifies the research gap from the literature review and proposes using the manufacturing management model to improve construction project management. Then, through the analysis of the features of the manufacturing industry, the IKEA approach is selected and analysed. Its applicability for construction project management is also discussed via the application of a questionnaire survey and comparison between IKEA furniture and the construction industry. VP technology, as a key technology that supports the use of the IKEA model in the construction industry, is customized. Following this, the IKEA model is applied to cast-in-situ and precast construction project management with the support of VP technology, that is the VP-based IKEA model. Finally, the feasibility and validity of this research is tested using a case study and the conclusion is drawn.

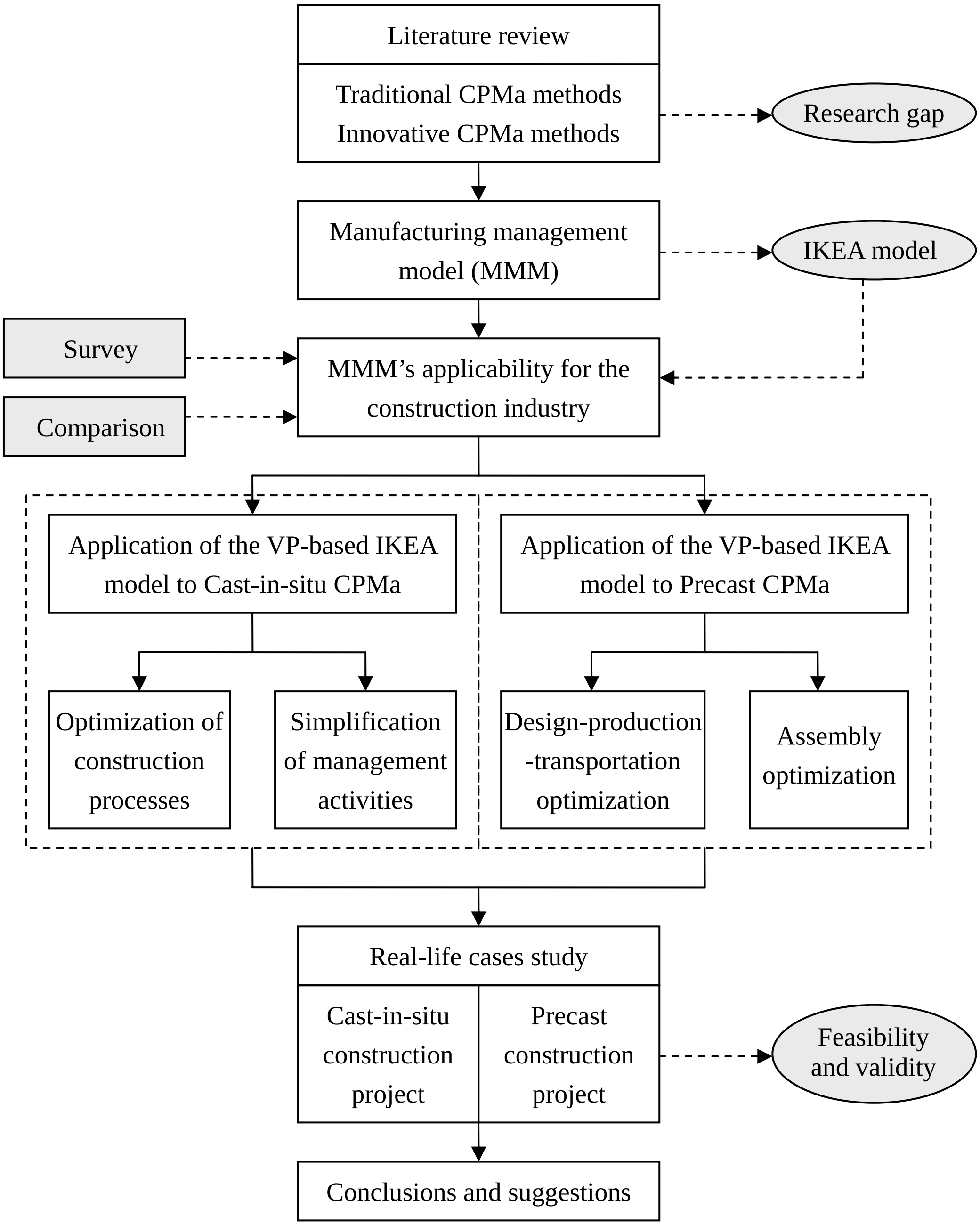


Figure 1.5 Logic framework of this research

1.5 Research Methodology

This research mainly relates to the improvement of construction project management using the VP-based IKEA model and therefore two aspects need to be paid attention to: the potential of the IKEA model for the construction industry and how to apply the model to the construction industry. For the former, the questionnaire method and comparison method are employed; and for the latter, the visualization method (i.e. VP technology) and cast study are adopted. Besides these methods, a literature review is also an important method herein.

1) A literature review makes the research gap clear through an analysis of the research and the practices of current construction project management methods and offers a background for applying manufacturing management methods to construction project management.

2) The aim of the questionnaire method here is to determine, using empirical data, the feasibility of the IKEA model to the construction industry. Thus the questionnaire survey is conducted in advance and the interviewees are researchers and practitioners in the field of construction project management. After getting the responses, the SPSS software package is used to analyse the empirical data.

3) The comparison method is used to discuss the feasibility of applying the IKEA model to the construction industry from the point of view of the features of the

two industries. The characteristics of the construction industry and products are compared with those of the IKEA furniture. Their similarities and differences are the objective factors of the successful application of the IKEA model to the construction industry.

4) VP technology, as an efficient visualization tool, offers an important support to the use of the IKEA model in the construction industry and is the key technology used to implement the application. It is employed to build the 3D models of construction projects, to detect some design problems, and simulate construction processes in advance based on the concept of the IKEA model in a virtual environment. This is determined by the difference between the construction industry and IKEA furniture.

5) Case studies are an important and effective method to demonstrate the effects of research. This research uses this method to test the feasibility and validity of the application of the VP-based IKEA model in the construction project management via two real-life cases.

1.6 Significance of the Research

The construction industry is an important and huge industry and relates to a lot of industries. However, its low productivity has a serious impact on its development. The identified traditional construction project management method, which leads to time and cost overruns, is the main reason for the low productivity. This research on the application of the VP-based IKEA model to construction project management will have a very important influence on the construction industry.

1) This research can improve the productivity of the construction industry. Applying the concepts of IKEA furniture to construction project management can optimize the design and construction process and simplify management activities. This reduces reworks and integrates management functions, and therefore construction time and cost is lowered and construction safety and quality is enhanced. Thus the productivity is improved and relevant industries may also be impelled.

2) An effective alternative for construction project management is offered. This research presents an innovative construction project management method through the combination of the IKEA model with VP technology. It remedies the shortcomings of traditional management methods and provides project management teams with an efficient management means.

3) This research makes a new attempt to apply the manufacturing management method to the construction industry. Due to their efficiency, there have been attempts in recent years to apply most manufacturing industry management methods, e.g. TQM, SCM, and LM, to construction project management with the

aim of improving the productivity of the construction industry. Using the IKEA approach in the construction industry is a new direction.

4) The adoption of VP technology herein contributes to the development of the use of advanced information technology to reform conventional industries (e.g. the construction industry). The construction industry, as a typical conventional industry, is characterized by low productivity. From the 1970s on, many construction and management methods have been developed and some of them continue to be practised. Although some IT technologies have been introduced into the construction industry, they are not widely used. Past research has focused on how to apply new technologies to improve this situation. This research offers a new direction for the use of IT in the industry.

Therefore, this research has not only theoretical value but also practical value for the field of construction project management.

1.7 Structure of the Thesis

This thesis involves seven chapters described as follows:

Chapter 1: Introduction The overview of the research is presented, including the research background, objectives, logic, methodology, significance and structure of the thesis.

Chapter 2: Literature review Both research and practice related to this research are reviewed, involving construction project management and VP technology.

Chapter 3: The manufacturing management model and its applicability to construction project management The features and successful factors of the manufacturing industry are analysed and the IKEA model is proposed. The feasibility of the IKEA model for construction project management is then discussed and VP technology is customized for this research.

Chapter 4: Using the VP-based IKEA model to improve cast-in-situ construction project management A method of application of the VP-based IKEA model to conventional construction management is proposed and analysis is focused on two aspects, i.e. optimizing the construction process and simplifying management activities.

Chapter 5: Using the VP-based IKEA model to improve precast construction project management Likewise, the application of the VP-based IKEA model to precast construction management is elaborated on and the optimization of design, production, transportation and assembly is investigated.

Chapter 6: A case study In order to demonstrate the feasibility and validity of the application of the VP-based IKEA model to construction project management, two real-life cases are discussed.

Chapter 7: Conclusions and suggestions for future research At the end of this thesis, the conclusions and suggestions for future research are presented.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

The research gap can be clearly identified by reviewing current and past research about practices related to construction project management (CPMa). Other successful attempts at applying new management methods and techniques to CPMa are also found to contribute to this research. This chapter reviews the definition of CPMa, traditional and innovative CPMa methods, and the application of advanced information technology (i.e. VP technology) in the construction industry.

2.2 Traditional Construction Project Management Methods

2.2.1 Definitions of Construction Project Management

To further review the definitions of construction project management will benefit the research on its innovation. The following presents two typical definitions of CPMa.

1) Walker (1984) defined *Construction Project Management* as:

"The planning, control and co-ordination of a project from conception to completion (including commissioning) on behalf of a client. It is concerned with the identification of the client's objectives in terms of utility, function, quality, time and cost, and the

establishment of relationships between resources. The integration, monitoring and control of the contributors to the project and their output, and the evaluation and selection of alternatives in pursuit of the client's satisfaction with the project outcome are fundamental aspects of construction project management."

2) According to the Project Management Institute of America, the discipline of project management can be defined as follows (Barrie and Boyd, 1984):

"Project management is the art of directing and coordinating human and material resources throughout the life of a project by using modern management techniques to achieve predetermined objectives of scope, cost, time, quality and participation satisfaction."

Construction project management, therefore, covers the whole process of a construction project and requires knowledge of modern management as well as an understanding of the design and construction process. The general functions of CPMa are as follows (Hendrickson, 2003):

- To specify project objectives and plans including delineation of scope, budgeting, scheduling, setting performance requirements, and selecting project participants.
- To maximize efficient resource utilization through procurement of labour, materials and equipment according to the prescribed schedule and plan.

- To implement various operations through proper coordination and control of planning, design, estimating, contracting and construction in the entire process.
- To develop effective communications and mechanisms for resolving conflicts among the various participants.

Most of these commonly belong to the design and construction process of construction projects and this has a direct impact on the cost, time, and quality of a project and determines whether it is successful or not. As a result, conventional CPMa targets design and construction process management. This, also, is the focus of this research.

Additionally construction project management is distinguished from the general management of corporations by the mission-oriented nature of a project. A project organization will be terminated when the project is accomplished. The general management of business and industrial corporations assumes a broader outlook with greater continuity of operations. Nevertheless, there are sufficient similarities as well as differences between the two so that modern management techniques developed for general management may be adapted for project management (Hendrickson, 2003). This underpins the application of the manufacturing management model (MMM) to the construction industry.

Therefore, besides traditional construction project management methods, some new

CPMa methods also occur through the application of new management techniques arising from other industries (e.g. TQM, SCM, LM) to improve the management level of construction projects. The subsequent sections review them further.

2.2.2 Traditional Construction Project Management Methods

The traditional construction project delivery approach is design-bid-build (D-B-B), that is, two different contracting efforts are undertaken in sequence to procure architecture/engineering (A/E) services on a negotiated-price basis (usually) and construction services on a lowest-responsible-bid or negotiated-price basis. Design work is done by a designer (i.e. an A/E firm) which provides a detailed plan and specifications for the general contactor. After the design is finished, the bid/build phase is started and the general contractor who wins the project is responsible for the construction itself even though the work may actually be undertaken by a number of specialty subcontractors. For a construction project, the construction phase occupies over half the time from conception to delivery, and most of the cost of the project also occurs in the stage. Therefore project management work mainly happens at this phase to control timing, cost and quality. Several common traditional construction management (CM) methods are reviewed as follows.

Critical Path Method (CPM)

CPM is the most common technique used in practice for construction planning and scheduling (Koo and Fischer, 2000) and is a network-based construction scheduling technique. Many existing software products such as Primavera Project Planner (2000) and Microsoft Project (2003) are based on CPM techniques for construction scheduling. CPM schedules are typically used to provide an overall view of the project, activity durations, sequences, milestones and criticality of activities.

The CPM model contains activities and precedence relationships. CPM computes project duration in deterministic terms by analysing which sequence of activities has the least float. Early start and finish times are computed using a forward-pass-algorithm, and late start and finish times using a backward-pass-algorithm (Moder et al., 1983; Barrie and Paulson, 1992; O’Brien, 1993; Patrick, 2004). The CPM algorithm defines the path (sequence of activities) that provides the shortest project duration among all possible paths. The main outputs are the range of possible activity times, critical activities and floats, and cost and resource information related to activities.

The CPM technique is mainly useful for master scheduling. The main limitations of CPM for operations management are as follows:

1) CPM schedules, when used for operations planning, become hard to manage, maintain and track because of the increased number of activities and relationships. Although PERT (Program Evaluation and Review Technique) networks can aid in

operations, increasing the number of sequencing relationships opens the schedule for inconsistencies.

2) CPM lacks information for resource levelling without the consideration of resource constraints (Peer, 1974; Laufer and Tucker, 1987; Leu and Yang, 1999; Zhang et al, 2006c). Therefore, it impossible to plan and optimize resource allocation through adopting CPM.

3) Activities do not represent production characteristics for construction. The CPM activities are the basic unit of analysis for the schedule and are aggregations of a set of construction processes, lacking information about the ways these processes are performed.

4) CPM is the lack of dynamic and stochastic characteristics of construction projects due to its deterministic and static representation nature (Halpin and Riggs, 1992; Sawhney and Abourizk, 1995).

5) CPM networks do not model work continuity for activities that are part of a wider workflow. It is very troublesome for the CPM networks to model the repetitive operations of activities, which are, however, often encountered in construction projects that contain several identical or similar units of work, as CPM needs to show all activity units and all linking arrows, resulting in a very large and

complicated network (Senior, 1995; Harris, 1998; Senior and Halpin, 1998). Line-of-balance (LOB) techniques aim to resolve this for linear or repetitive activities.

Look-ahead Schedule

A common industry practice to overcome the shortcomings of CPM schedules for operations planning is to use look-ahead or short-interval schedules to show near-term activities (commonly a two or three week range) in more detail than the master schedule. Several previous research efforts have identified the value of and the need for look-ahead schedules (Ballard, 1997; Hinze, 1998). However, look-ahead schedules are rarely conceived with the specific purpose of producing sound assignments, nor are procedures provided for look-ahead processes. They are prepared manually or by using a set of heuristics from the master schedule and resource input. Therefore, the consistency between the master schedule and the look-ahead schedules is limited.

Similar to the CPM networks, look-ahead schedules do not explicitly relate to the spatial aspects of a project. In areas where spatial interactions are critical, site personnel develop hand-coloured blueprints to evaluate and explain actual or planned work progress. In addition, look-ahead schedules are done shortly before construction, so the opportunities to identify possible problems and proactively consider alternative workflows are limited.

An even more detailed approach is weekly work plans, developed by the foremen of crews who will actually perform the work (Gil et al., 2000). Two related systems facilitate this. Last Planner (Ballard, 2000) defines a methodology to generate assignments for look-ahead schedules and weekly work plans, and WorkPlan (Choo, 2003) facilitates ways to coordinate these plans among project participants. Again, the connections to the master schedule are limited at this level of detail and there is no link to the geometric model of the project.

Linear Scheduling Model

Another group of scheduling techniques, mainly for linear and repetitive activities, is linear scheduling or line-of-balance (LOB) techniques. The purpose of these techniques is to ensure that each resource can progress from one activity to the next in an orderly way, and provide continuous utilization of resources if necessary. The diagrams for these techniques represent the progress information linearly or unit by unit, so they are limited to linear or repetitive tasks in construction (Kavanagh et al., 1985; O'Brien, 1975; Selinger, 1980; Stradal and Cacha, 1982).

This technique, originally developed for industrial production planning (Lumsden 1968), analyses the required rate of finished products and builds up the necessary production rates of all assemblies feeding into the finished product, all the way back to the ordering of materials.

In building construction, trades move from location to location in 3D around installed components and complete the work that is prerequisite for the following trade. Furthermore, LOB, in a diagram form, can only present a limited amount of information. Many extensions are needed for these techniques to support construction work in general (Arditi et al., 2002). There have been various efforts to combine CPM and LOB (Perera, 1982; Russell and Wong, 1993; Suhail and Neale, 1994).

As an extension of LOB methods using 3D geometric models, Thabet and Beliveau (1997) describe a planning and scheduling technique based on the space use of activities for multi-story building construction. They consider space as a consumable resource and describe the space consumption of each crew over time. They abstract activities into different classes based on space requirements and consider the workflow direction for each crew as either horizontal or vertical. They decompose the project geometric models into structure grid blocks and analyse each space separately. The spatial information that drives the scheduling process is the enclosed space of the grids, instead of components enclosed in the space. Additionally, their technique supports only basic spatial analysis.

Therefore, the traditional construction process planning and management methods mentioned above cannot be employed to make a detailed construction schedule for an entire project because of the large amount of information and the interdependence between different elements. Additionally, the capability of visualizing and understanding the construction process is also limited using these methods. It is almost impossible for the project team to execute an effective and streamlined construction plan through the traditional construction process planning methods. Because of the shortcomings of traditional construction planning methods, it can be concluded that a more effective construction management method is needed.

Design-build (D-B) Delivery Approach

Design-build is a project delivery method in which the design and construction of a project are combined into one contract, usually awarded on either a low bid or best-value basis (Beard et al., 2001; Friedlander, 1998). It represents one of the most promising yet controversial methods for streamlining the project development function and potentially lowering project cost and duration while maintaining or improving product quality. In the D-B approach, the designer and general contractor are an integrated team that works concurrently on the design and construction phases of different segments of a project, with the potential to expedite delivery and better control product quality and costs.

A number of advantages over typical contracting (e.g. D-B-B) have been proclaimed as follows (Loulakis, 1999; Pakkala, 2002; Tenah, 2001):

1) Time savings

- Early contractor involvement that enables construction engineering considerations to be incorporated into the design phase and that enhances the constructability of the engineered project plans;

- Fast-tracking of the design and construction portions of the project, with overlapping;
- Concurrency of design and construction phases for different segments of the project; and
- Elimination of a separate construction contractor bid phase following completion of the design phase.

2) Cost savings

- Communication efficiencies and integration between design, construction engineering, and construction team members throughout project schedule;
- Reduced construction engineering and inspection costs to the contracting agency when these quality control activities and risks are transferred to the design-builder;
- Fewer change and extra work orders resulting from more complete field data, and earlier identification and elimination of design errors or omissions that might otherwise show up during the construction phase;
- Reduced potential for claims and litigation after project completion as issues are resolved by the members of the design-build team; and
- A shortened project timeline that reduces the level of staff commitment by the design-build team and motorist inconvenience due to reduced lane closures.

3) Improved quality

- Greater focus on quality control and quality assurance through continuous involvement by the design team throughout project development; and
- Project innovations uniquely fashioned by project needs and contractor capabilities.

Design-build contracting has become a popular form of project delivery for private firms and public agencies responsible for the development of buildings and other types of vertical infrastructure. By the end of the last decade, design-build contracting had grown to almost one-quarter of the total dollar volume of non-residential construction in the US, according to the Design-Build Institute of America (SAIC et al., 2006). Much of this activity has been for buildings, with the private sector most heavily committed to this form of facilities development contracting. In Hong Kong, the government (e.g. Architectural Services Department, ASD) also gives a great impetus to the implementation of D-B delivery projects.

Although the D-B delivery approach improves, to some extent, the construction management of projects, especially in theory, the advantages of D-B are not applied fully. On the one hand, the traditional construction management methods have not yet changed in the D-B approach delivery and the improvements in the delivery approach (from D-B-B to D-B) are not enough to significantly improve construction productivity. On the other hand, a lack of an effective and efficient communication and collaboration means or platform makes it difficult to realize the communication and coordination benefits between designers and constructors in the D-B approach. Nevertheless the D-B delivery approach provides a great support to the introduction of new management techniques to the construction industry.

2.3 Innovative Construction Project Management Methods

Innovation is always important to the continuous development of the construction industry. Sims (1968) proved that productivity in USA construction industry was significantly increased during the period from 1947 to 1968 due to technological innovation. Toole (1998) defined construction innovation as the “Application of technology that is new to an organization and that significantly improves the design and construction of a living space by decreasing installed cost, increasing installed performance, and/or improving the business process”, while the Construction Research and innovation Strategy Panel (CRISP) (1997) said that “The successful exploitation of new ideas, where ideas are new to a particular enterprise, and are more than just technology related – new ideas can relate to process, market or management”. The innovation of construction project management methods is defined by this research as “the successful application of new concepts with the aid of new technology to improve the holistic process of construction projects, where concepts and technology are new to the construction industry”. Many researchers and practitioners in the construction industry have made a great deal of effort to improve the construction management innovation, aiming to improve the performance of construction management and the productivity of the industry. This comprises the application of new management methods (e.g. TQM, SCM, and LM) from other industries (e.g. the manufacturing industry) and the innovation of construction process management, which are reviewed in the following sections.

2.3.1 Application of New Management Methods to CPMa

Application of TQM to CPMa

The conception of total quality management (TQM) was first conceived by Dr. W. Edward Deming in the 1950s, first applied in Japan and has in recent years been used in the United States. It has increased productivity, decreased product cost and improved product reliability. It has also been adopted in other countries and regions, for example the electrical and electronic engineering industry in Malaysia (Idris et al., 1996), UK companies (McCabe, 1996), and manufacturing companies in Singapore (Ghosh and Wee, 1996).

TQM may be presented in various theoretical forms, but its fundamental goals are customer satisfaction and continual improvement. From Dale and Plunkett (1991), TQM not only improves productivity, higher standards, systems and procedures, motivation, and customer satisfaction, but also lowers costs to bottom line savings. Hudiburg (1992) described the object of TQM as follows:

“The object of total quality management is simple: to establish a management system and corporate culture that will assure higher customer satisfaction than your competitors”.

Due to the success of total quality management (TQM) practices in the manufacturing industry, much attention has been paid to its application in the construction industry (Aoieong et al., 2002). For example, Japanese construction companies, benefiting from the experiences of Japanese manufacturers, began implementing TQM during the 1970s (Arditi and Gunaydin, 1997). Even though construction is a creative, one-time process, the Japanese construction industry embraced the TQM concepts that some argued could only apply to mass production. It is believed that the benefits of higher customer satisfaction, better quality products, and higher market share are obtained following the adoption of TQM by construction companies.

TQM is often termed a journey, not a destination (Burati and Oswald, 1993). It involves every organization in the industry in the effort to improve performance, permeates every aspect of a company and makes quality a strategic objective (Burati et al., 1992). The success of TQM requires an integrated effort among personnel at all levels to increase customer satisfaction by continuously improving performance. Oakland (1995) observes that in essence it is a way of planning, organizing, and understanding each activity that depends on each individual at each level. TQM focuses on process improvement, customer and supplier involvement, teamwork, and training and education in an effort to achieve customer satisfaction, cost effectiveness and defect-free work, and provides a culture and climate essential for technological advancement and innovation (Arditi and Gunaydin, 1997).

Much research has been done with regard to the implementation of TQM in the construction industry. According to Quazi and Padibjo (1997), TQM requires a complete turnaround in corporate culture and management approach as compared to the traditional way of top management giving orders and employees merely obeying them. Motwani (2001) feels that the implementation of TQM is a major organizational change that requires a transformation in the culture, process, strategic priorities, beliefs, etc. of an organization. Arditi and Gunaydin (1997) discuss the implications of TQM in the construction industry. Low and Peh (1996) outline the basic steps to implementing TQM in construction projects: 1) to obtain the commitment of the client to quality; 2) to generate awareness among, and to educate and change the attitudes of staff; 3) to develop a process approach toward TQM; 4) to prepare project quality plans for all levels of work; 5) to institute continuous improvement; 6) to promote staff participation and contribution using quality control circles and motivation programmes; and 7) to review quality plans and measure performance. Low and Jasmine (2004) propose how TQM can be applied more actively in the construction industry, i.e. to address the issue of applying TQM in the construction industry, to examine possible steps for restructuring an organization for TQM, and to propose an implementation framework for TQM. All of these move the application of TQM in the construction industry and also enlightens this study.

Despite the benefits, TQM has not yet been widely adopted in the construction industry. The biggest hurdle is to change the status quo of the organization and develop a culture that will support TQM. Some other reasons also impeding the extension of TQM include: managers' failure to understand TQM, high initial cost, the multi-organizational structure of the construction industry and construction projects, etc.

Application of SCM to CPMa

Supply chain management (SCM) also originated and flourished in the manufacturing industry. It first appeared in the JIT (Just-in-time) delivery system, as part of the Toyota Production System (Shingo, 1988; Wong and Fung, 1999). TQM also stimulates the development of SCM (Vrijhoef and Koskela, 2000); Deming (1982) suggested that working with the supplier as a partner in a long-term relationship of loyalty and trust would improve the quality and decrease the costs of production. After its emergence in the Japanese automotive industry as part of a production system, the conceptual evolution of SCM has resulted in an autonomous status of the concept in industrial management theory, and it has become a distinct subject of scientific research, as discussed in literature on SCM (e.g. Bechtel and Yayaram, 1997; Cooper et al., 1997). In addition to Japan, western scholars (e.g. Burbridge and Forrester) provide early contributions to the understanding of supply chains (Towill, 1992). Along with original SCM approaches, other management concepts (e.g. value chain, extended enterprise) have influenced its conceptual evolution, which has led to the present understanding of SCM.

SCM is the process of planning, implementing and controlling the operations of the supply chain as efficiently as possible. It spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point-of-origin to point-of-consumption. SCM not only increases the internal efficiency of organizations but has been broadened to reduce waste and add value across the entire supply chain (New and Ramsay, 1997; Harland et al., 1999). It is an important element in the innovation of products, processes and organizations (Holti, 1997).

SCM is also seen as a set of practices to manage and coordinate the whole supply chain from raw material suppliers to end customers (Vollman et al., 1997). It effectively integrates all the organizations involved (von Hippel, 1986) through upstream and downstream linkage (Harland et al., 1999; Christopher and Juttner, 2000), and makes information easily shared, and knowledge easily identified, captured and disseminated throughout these organizations (Edum-Fotwe et al., 2001). It further leads to greater openness and transparency in transactions, and increases trust and commitment (Ali et al., 1997). This strongly benefits the development of more effective and longer-term relationships between buyers and suppliers (Spekman et al., 1998; Kosela, 1999).

Following the successful examples of other sectors, from the end of the 1980s, the construction industry has seen the launch of a number of SCM initiatives. A survey from Saad et al (2002) shows that the construction industry is moving toward the adoption of SCM and both project processes and supply networks, which lack strategic supplier partners, are being restructured and integrated. This incorporates continuous improvement targets to reduce costs, and enhance quality, and focuses on the whole-life cost and functional performance of buildings (Holti et al., 1999; Vrijhoef and Koskela, 2000).

However, until now the application of SCM in the construction industry has been scattered and partial. This is due to some barriers, such as a lack of common purpose and openness, hidden goals, opportunistic behaviour and a misunderstanding of SCM (Saad et al., 2002). In the traditional procurement approach, most partnering focuses on collaboration in upstream relationships between regular and frequent clients, consultants and main contractors (Bresnen and Marshall, 2000; Edum-Fotwe et al., 2001), with less involvement of downstream organizations, such as trade subcontractors, and suppliers during the process (Jones and Saad, 1998; Akintoye et al., 2000). This conflicts with the successful implementation of SCM (New and Ramsay, 1997; Spekman et al., 1998; Harland et al., 1999).

Application of LM to CPMa

Lean manufacturing (LM) or lean production (LP) is the optimal way of producing goods through the removal of waste and implementing flow, as opposed to batch and queue. It is a generic process management philosophy derived mostly from the Toyota Production System (TPS) (Womack et al., 1991) and can be regarded as a development of JIT (Just-in-time). The ideas of lean thinking comprise a complex cocktail of ideas including continuous improvement, flattened organization structures, teamwork, the elimination of waste, the efficient use of resources and cooperative supply chain management (Green, 1999 and 2002).

Lean manufacturing has proved a major competitive advantage to Japanese manufacturing companies. In the 1980s, LM was implemented by US manufacturing companies and also improved their operations (Womack and Jones, 1996). Lean thinking subsequently became the generic term to describe their universal application beyond manufacturing (Womack and Jones, 1996). Since Koskela’s (1992) seminar report was published, which put an emphasis on the production process flow, i.e. aspects related to converting inputs into finished products as an important element to reduce wasted value on jobsites, many researchers have been studying the application of LM to construction, e.g. Alarcon (1997), Tommelein (1998) and Thomas et al. (2003). This is called lean construction (LC).

Lean construction has important differences from current practice. In both approaches a design brief is prepared, the design developed and engineered and materials purchased, fabricated and installed. Under lean construction, the work in each of these activities is different and lean construction adds two essential concepts: works structuring and production control. Researchers in construction have begun to realize that construction management must include production control systems (Bernold and Salim, 1993; Melles and Wamelink, 1993) to complement the project management systems. In general, lean construction: has a clear set of objectives for the delivery process; aims at maximizing performance at the project level; designs the product and the process concurrently; and applies production control throughout the life of the project.

Some lean concepts have been applied to construction. Howell et al. (1998) discussed how buffers of materials can alleviate dependencies and worker idle time otherwise incurred when process subcycles interact with one another. Tommelein (1998) adopted the LC idea to simulate and manage the delivery of material for pipe-spool installation. Ballard (2000) formalized the Last Planner to shield installation crews from uncertainties in work flow and demonstrated its successful implementation on actual projects.

Similarly to TQM and SCM, lean construction is still not well implemented well in the construction industry. The main reasons for this are as follows: 1) lean construction emphases reliable workflow than local speed and cost and this is opposed to current construction practice; 2) the organizational aspects of lean construction conflict with current (if unstated) principles: current practice rests on an activitycentred model that more or less ignores the flow and value issues while the system thinking of lean construction always raises the issue of responsibility to new levels; and, 3) lean construction decentralizes decisions that change the current hierarchical nature of construction organizations. Therefore, this needs further research.

Fortunately, construction project management trends towards partnering and relational contracting and the primary trusts can be provided for multi-parties long-term coordination. This provides an important support to the success and extensive application of these new management concepts to construction project management.

2.3.2 Innovation of Construction Process Management

A lot of research has been conducted into innovative construction process planning. This is described in the following section.

Automated Process Planning Method

Automated process planning methods, based upon knowledge (cases), and artificial intelligent (AI), etc., automatically generate tasks required to reach a goal state, assign resources to tasks, sequence these tasks, and calculate their durations. Its aim is to automate this process for construction, prepare a construction plan or a schedule, and assign required resources for the process of interest (Zozaya-Gorostiza et al., 1989).

Existing research on automated planning is relevant in several ways. Such research includes research into capturing planning methodology, managing the process level of detail, and spatial content and reasoning. Automated process planning methods mainly use two strategies for planning: top-down or bottom-up. Top-down planning uses elaboration (or task-decomposition) mechanisms to generate a detailed plan from a general plan, making use of the physical organization of the project. The elaboration mechanism stops when the most detailed representation of the components is reached, in which case activities associated with the components are created. In some cases, these methods aggregate the activities to an appropriate level of detail. OARPlan (Darwiche et al., 1989) associates components and activities as pairs at the beginning of the planning process and keeps that association fixed during planning. In effect, this requires a joint hierarchy for both the activities and components and prevents independent generation of these hierarchies. This approach generates activities using the product structure. ZonePlanner (Winstanley and Hoshi, 1993) is an extension of OARPlan, which tries to optimally aggregate detailed sets of activities to create sub-networks.

An example of a bottom-up planner is Planex (Zozaya-Gorostiza et al., 1989). Planex utilizes a coding scheme based on Masterformat to obtain a hierarchical organization for both components and activities by material, component type, and location. Its first planning step is decomposing the model of the finished facility into primitive design elements. Planex then determines the activities required to produce each design element, which are called element activities. Subsequently, it aggregates element activities into project activities. The location information describes a fixed and predefined (floor, sector, and project) spatial decomposition for the project which needs to be manually assigned to each component. This is limiting, because planners might have different preferences in the physical organization of the process compared with the organization of the finished facility.

Automated process planning commonly uses physical support relations to determine the sequence of activities, e.g. Planex (Zozaya-Gorostiza et al., 1989), Ghost (Navinchandra et al., 1988), Builder (Cherneff et al., 1991), CMM (Fischer and Aalami, 1996). The supporting component should be installed before the supported component can start. For example, footings must be installed before work on columns can start. Similarly, some activities cannot start unless its required work is ready. For example, scaffolding should be installed for the activity that requires scaffolding to start. Echeverry et al. (1991) describe general factors for the sequencing of construction activities, including physical relationships among building components, trade interactions, path interference, and code regulations.

There are two significant limitations of existing research on automated construction process planning methods. One is their low optimization capability. All of these methods implement the automatic generation of construction process plans to some extent, but they cannot optimize a construction plan. Project planners must compare them one by one to get an optimal plan alternative. In addition, the ability of automatic planning is not enough to develop the construction scheduling of a whole project.

Another one is their limited visualization or spatial analysis capability. Planex and OARPlan use axis-aligned prismatic shapes for component geometry. Component geometry is kept fixed throughout the planning process and there is limited consideration of local geometric properties. The activities generated depend on the most detailed component representation and the original organization of the project.

Some automated process planning methods utilize geometric models during the planning process. Morad and Beliveau (1994) presented an automated planner, KNOW-PLAN, which uses information extracted from 3D CAD models in its reasoning. KNOW-PLAN extracts the bounding box information for 3D CAD models and performs basic spatial analysis, such as calculating height differences and sorting components in a single axis for planning purposes. It then sequences the activities using a set of rules. Cherneff et al. (1991) developed Builder, which has a CAD modeller and uses sequence, production rates, and resource availability to determine the plan. CMM (Aalami, 1998) defines the construction method model templates extending the OARPlan methodology so that planners can automatically develop schedules from CAD models. CMM supports general geometric models and performs simple spatial analysis but gives inadequate consideration of important geometric elements for the planning process. For example, it sequences work without an underlying directional workflow strategy. Vries and Harink (2007) described a 3D-based method for automated generation of the construction planning. An algorithm was presented that derives the construction order from a solid model of the building. However, this aspect needs to be further studied.

Simulation-based Process Planning Method

Simulation technology has been proven to be an effective tool for improving construction process planning (Halpin and Riggs, 1992). Especially, since discrete event simulation (DES) was introduced to construction processes with the development of the CYCLONE modelling methodology (Halpin, 1977), it has been applied to much construction research on design and analysis of construction processes. Various construction simulation tools have been developed based on DES, for example INSIGHT (Paulson, 1978), RESQUE (Chang, 1987), UMCYCLONE (Ioannou, 1989), COOPS (Liu and Ioannou, 1994), DISCO (Huang et al., 1994), CIPROS (Tommelein and Odeh, 1994), STROBOSCOPE (Martinez and Ioannou, 1994), HSM (Sawhney and AbouRizk, 1995), and ACPSS (Liu, 1996). DES has been an alternative to aid project planning or scheduling (Carr, 1979; Woolery and Crandall, 1983; Ahuja and Nandakumar, 1985). It has some advantages over CPM due its ability to carry out what-if analysis for investigating impending and potential problems by considering the stochastic and dynamical natures of construction processes. For example, the tools mentioned above can provide information about resource utilization, resource allocation rules, operation bottlenecks, and production rates.

However, simulation models have limited successful applications to construction practice, mainly because of complexities involved in constructing a model and the resultant time required (Shi and AbouRizk, 1997). Further to this: 1) Most simulation tools require many kinds of modelling elements, which may increase the complexity of the graphic networks and result in spending more time in differentiating the types of activities; 2) It is difficult to use some simulation systems because of the requirement of programming, which normally takes users much time to learn and to become acquainted with the simulation languages; 3) The verification of a simulation model and validation of simulation results are crucial: this requires comprehensive skill and experience (AbouRizk et al., 1991), but most systems lack an easy-to-use method to accomplish this, especially for common users without adequate simulation knowledge and experience; 4) Unlike CPM, it is difficult to understand and interpret statistical simulation results, especially when the construction system under study is very complicated. All of these factors greatly limit the efficiency of these simulation tools and their applications to the construction field; and 5) Its result and process is still not visualized, and the spatial analysis cannot be executed in DES.

Some research aiming to address the above shortcomings has been conducted. Shi (1997 & 2001) studied the activity cycle-based modelling (ACBM) method to translate the activity cycle diagrams (ACD) statements of a process into an equivalent executable SLAM II simulation model. The translation can be automated by implementing generalized rules into a computer system. This approach simplifies the modelling task for a construction process into defining an activity cycle diagram, which is much easier than directly constructing a simulation model.

Zhang et al. (2002b) developed a combination model of CPM and DES controlled by the activity scanning (AS) strategy, an activity-based graphical model, an AS-based forward pass, and a backward search algorithm to perform scheduling analysis. Compared with CPM and other simulation-based methods for scheduling, the model is able to deal with more complex situations in construction, such as complex logical dependencies between activities, complex or unbalanced resource involvements, and repetitive activity operation, which the CPM network has trouble dealing with.

Chua and Li (2002) presented a resource-interacted simulation (RISim) modelling method that enables site managers to develop simulation models in a way that they would naturally conceive of the problem, rather than through a specific simulation language. Using object-oriented modelling concepts, RISim models take resources as objects and emphasize the characterization and interaction of resources. Such an approach can present an alternative simulation methodology that can enable site managers with site process knowledge but little knowledge of simulation to build the models on their own.

Lee and Arditi (2006) presented a stochastic simulation-based scheduling system (S3), which integrates the CPM, the probabilistic program evaluation and review technique (PERT), and the stochastic discrete event simulation (DES) approaches into a single system and improves the accuracy of simulation results.

Shi (1999) proposed the activity-based construction (ABC) modelling method be used to model construction processes. Unlike other simulation systems for construction operations, for instance CYCLONE and STROBOSCOPE, which use multiple kinds of modelling elements to model real systems, the ABC modelling requires only one kind of element, i.e. the activity, to model construction operations. The graphical model resembles the CPM, which is easily understood by construction users and looks simple. Also the ABC modelling can deal with the repetitive operation of activities or repetitive resource utilization, which is not considered by CPM. However, the disadvantages of the ABC method are: 1) less visible logical information in a graphic network; 2) that the model is not appropriate for complicated construction process scheduling; and 3) that information hidden behind each activity is required to be inputted.

Some researchers also study techniques to visualize the results of DES of construction processes based on 2D or 3D models. Ioannou et al. (1996) create a text file during simulation to drive 2D visualization software and animate the simulation results by changing the position, shape, and colour of icons to represent resources on 2D drawings. Kamat and Martinez (2001) extend this idea to 3D visualization tools, generating a text file as an output from STROBOSCOPE to graphically illustrate the construction operations as simulated in 3D. Zhang et al. (2002a) used visual technology as a solution for some of shortcomings. He developed a visual simulation environment, especially an easy-to-use animation, which aims at enhancing the modelling efficiency and modelling power. Pang et al. (2006) studied the usefulness of Cell-DEVS in sensitivity analysis considering different worksite layouts. Comparison between cell-based modelling and Micro-CYCLONE had been made to show the feasibility of Cell-DEVS (Wainer, 2002; Wainer and Giambiasi, 2002). The Cell-DEVS model has been improved by incorporating more complex rules to detect and solve spatial conflicts, and to calculate delays. Zhang et al. (2007) have investigated the application of Cell-based modelling to construction simulation. Spatial conflict detection is applied in cell-based modelling, and is based on an explicit representation of the worksite, which is not available using MicroCYCLONE. However, the spatial content in the 3D models is not part of the simulation, and the geometric models still need to be manipulated for visualization purposes.

As a whole, these studies still have some drawbacks as follows: 1) The spatial analysis for construction process cannot be executed; 2) Resource allocation or levelling is little analysed; 3) The construction scheduling cannot be automatically generated; and 4) The optimization methods are little applied to the simulation. Therefore, visualization methods and optimization methods should be introduced into the simulation-based planning method.

Visualization-based Process Planning Method

Visualization is a graphical representation of data and concepts (Ware, 2000). It provides ways to convey information derived from a model, relying on users for interpretation and pattern detection. Due to the requirements of construction processes and the improvement of digital technologies, more and more research has been conducted on developing visualization-based process planning modeling.

During the past two decades, advances in three-dimensional (3D) computer-aided design (CAD) technologies have furnished the opportunity for enterprises to apply 3D models to manage construction information in projects, by viewing static realistic images. However, these 3D models by themselves, without the ability to display the exact status of a project at a specified period, furnish little assistance in progress control. There is no data integration and interaction between the 3D model, schedule information and other data. In order to produce a construction schedule from 3D drawings, planners have to envision the sequence of construction in their mind. This is a very difficult task since workspace logistics and the utilization of resources and equipment are, by their very nature, highly dynamic. In practice, most site organizations often plan their works based on the inception site layout and utilization drawings, which are rarely updated during the project duration. Thus, in real terms, site managers have not fully benefited from recent advancements in computer technology.

The 4D (3D plus time) is a geometry-based construction process visualization technique (Koo and Fischer, 2000), combining the 3D model and time. Its basic goal is to create a time-lapse visualization of a construction process by association of components and CPM schedule activities. It visualizes the installation states (the start and finish dates of activities) for the 3D geometry of the finished facility by colour-coding associated activity types. 4D models use a discrete-time scale; changing the project time gives a visualization of the project states for that given time.

The four-dimensional (4D) geometric model has been employed in some research on construction project planning. Retik et al. (1990) discussed the possible use of computer graphics as a scheduling tool. Williams (1996) generated a 4D movie or animation film of a series of activity queues to help understand the construction plan realistically. Collier and Fischer (1996) linked layers in a 3D-CAD model to construction activities in a construction project. McKinney et al. (1996) presented a prototype 4D tool to allow planners to manually generate CAD, schedule, and 4D content. Adjei-Kumi and Retik (1997) presented a library-based 4D model for planning and visualizing the construction plan. McKinney and Fischer (1998) gave an overview of generating, evaluating and visualizing construction schedules with CAD tools. Liston et al. (1998) developed a 4D-CAD visual decision support tool for construction planners, with visual cues for quick identification of problem areas.

Staub-French et al. (1999) illustrated that 4D simulation was better for construction planning than Gantt charts or CPM schedules. Koo and Fischer (2000) showed that 4D models are effective in evaluating the feasibility of a construction schedule and highlighted the need for improvements to 4D tools. Kamat and Martinez (2001) described a system to enable spatially and chronologically accurate 3D visualization of specific construction operations. Kamat and Martinez (2002) capitalized on a computer graphics technology based on the concept of the scene graph. Chau et al. (2003) implemented a 4D management approach to construction planning and site space utilization. Dawood et al. (2003) reported on the development of an integrated database for 4D construction process simulation. Wang et al. (2005), Ma et al. (2005), and Chau et al. (2005) applied 4D models to the site planning and management of construction projects.

A 3D model can enhance the visualization of the project, while the visualization of construction plans enables planners to share complex ideas. It encourages them to be more creative in providing and testing solutions by means of viewing the simulated time-lapse representation of corresponding construction sequences (McKinney and Fischer, 1997). Koo and Fischer (2000) and McKinney and Fischer (1997) concluded that the 4D model is an effective means for communication and provide spatial information to the project. The advancement brought by the 4D model is believed to have strong potential and will have a significant impact on construction management practice (Chau et al., 2005). Through using the 4D model, different solutions for construction scheduling can be tested.

However, 4D models cannot convey all the information, for example resources, material, etc., required to evaluate the construction schedule and are typically more useful at a whole project level than at an operational level. The main reason for this is that it is founded on the CPM method and 3D geometry inputs. On the one hand, it carries over some limitations of the CPM. For example it assumes the production rate is constant for the duration of an activity, and it does not capture or visualize the reasons behind an existing plan or any geometric planning parameters, such as workflow directions. On the other hand, in order to match the geometric representation with the process description, it requires the manipulation of geometry inputs and scheduled activities, and the associating of the resulting elements. This is time consuming, error prone, and it makes no explicit use of construction process information for geometry and activity manipulation. Whenever a change occurs in the plan, the 4D model needs manual updates. Therefore, it is impractical to consider many alternatives with 4D models.

Optimization Method of Construction Process Planning

For a construction project, the project manager wants to get an optimal construction process, while satisfying some constraints, for example resource allocation, construction time and cost budget. This can reduce rework and save cost and time. However, in practice, it is difficult to find such an appropriate construction process.

The focus of research on optimization methods is mainly on resolving this problem. Commonly, the time-cost optimization is the major target of optimization methods.

Optimization for construction process scheduling refers to a process to find an appropriate construction sequence for all activities through the analysis of time-cost optimization by using some algorithms. It is commonly implemented using simulation technology. However, optimization routines and simulation environments are often incompatible because the modelling techniques of simulation and mathematics are so different. Some researchers have conducted research on optimization methods of construction process scheduling. Many optimization methods have been developed for simulation models (Azadivar, 1992). Azadivar (1992) categorized these methods as follows: 1) gradient-based search methods; 2) stochastic approximation methods; 3) response surface methods; and 4) heuristic search methods.

Gradient-based search methods and stochastic approximation methods focus on continuous movement toward the optimum. These techniques assume unimodal solution functions and contain algorithms to identify the direction of the steepest slope. Riggs (1976) developed an automated sensitivity analysis module for CYCLONE that required the user to provide the upper and lower limits of the resource quantities available for the operation being modelled. Using this method, the user is able to establish the direction toward which the optimal resource configuration may be found.

The response surface methodology involves fitting regression models to the results of the simulation run evaluated at various states of the problem domain. Azadivar and Talavage (1980) showed that the effectiveness of this method was greatly reduced if the regression function contained sharp ridges or flat surfaces.

Heuristic methods may not guarantee that the solution found is the global optimum because there is often no assumption that the solution function is unimodal. One may be confident that the solution found by the method is very good, but it may not be the optimum. Two formal heuristic methods have been defined by Azadivar (1992): complex search and simulated annealing. Methods that rely upon artificial intelligence, such as genetic algorithms, rule-based systems, and belief networks also fall into this category. This method is used widely in construction processing scheduling.

Complex search involves using the results of several simulation runs from different variable parameters to determine the worst point. The worst point is dropped, a new point is generated, and the simulation is rerun. Simulated annealing is a local gradient search method that evaluates the objective function, for example to minimize the cost, at an appropriately chosen point. If the new cost is less than the cost at the previous point, then the new point is accepted and the old one is dropped. To reduce the likelihood of being caught in a local minimum, the method will allow uphill moves based on random variables with controlled probabilities.

Some heuristic techniques have been developed specifically for improving construction operations, and most of them are based on some priority rules, such as MINTF (minimal total float), MINLFT (minimal late-finish time), MAXEST (maximal early start time), or WC (work content equalling the number of resources times the activity duration). Wood and Harris (1980) developed a program that utilized an iterative technique of simulation and manual cost evaluation to optimize concrete delivery truck fleets. The model is able to analyse various truck and plant capacities.

Badiru (1991) proposed simulation as a useful analytical tool for project network analysis. A computer program, named STARC, was used to illustrate the effectiveness of computer simulation for project planning. STATGRAPHICS software was used to illustrate some of the post-simulation statistical analyses that could be conducted.

Padilla and Carr (1991) developed a dynamic-strategy model, which was a Monte Carlo simulation-based program to explore alternative resource-allocation strategies for construction projects that had uncertain activity durations and costs. It extends resource allocation beyond current models that assume activities' durations are deterministic. In projects of uncertain duration, 1) activity duration and cost depends on resource assignment; 2) good resource assignment depends on random variables that influence duration and cost; and 3) outcomes of these random variables are not known until the project is built. The model assigns resources during the simulation of project progress by encapsulating decision rules to describe dynamic strategies that fit samples of labour and material costs, weather, productivities, and other random variables.

Boctor (1993) used heuristics in construction planning with resource restrictions and several resource-duration modes.

AbouRizk and Shi (1994) applied heuristics to a DELAY statistic to determine whether the number of resources in a simulation model should be increased or decreased in order to meet project objectives for optimizing cost, production, or resource utilization. The DELAY statistic is equal to the fraction of time, and a resource is idle relative to its total working time.

Shi and AbouRizk (1995) developed a hybrid simulation and mathematical optimization system for handling large, complex systems. In this model, the large system is broken into smaller sections for separate evaluation of each feasible resource state. The smaller sections are rejoined by mathematical functions and the entire project is optimized mathematically. The method requires significant manipulation by the user to determine the connection types between the smaller simulation model sections, development of the mathematical functions that connect the smaller sections into the entire project, and fine-tuning.

Tompkins and Azadivar (1995) combined genetic algorithms with object-oriented programming in ModSim II to develop a means of optimizing simulation models for manufacturing systems. The system is intended to represent corporate policy for minimizing resource requirements of new operations. Several billion points could be searched to result in significantly improved solutions over random search methods.

Chan and Chua (1996) proposed a new approach for resource scheduling using genetic algorithms (GA). The methodology does not depend on any set of heuristic rules. Instead, its strength lies in the selection and recombination tasks of the GA to learn the domain of the specific project network. This way, it is able to evolve improved schedules with respect to the objective function. Further, the model is general enough to encompass both resource levelling and limited resource allocation problems unlike existing methods, which are class-dependent.

Chan and Chua (1996) developed a hybrid optimization system using genetic algorithms and computer simulation for use in civil engineering applications. Because of the constraints imposed by practical issues of the specific applications, they found that the genetic algorithms did not give fully optimal the solutions.

Tsai and Douglas (1998) applied tabu search to schedule activities of stochastic resource-constrained projects.

Li (1998) proposed an application of Petri nets in assisting the framework of process improvement in the construction industry. He described how Petri nets could be used to describe the workflow of a re-designed process, and demonstrated how to identify and select which aspects of the workflow to re-design. After the process is re-designed, the Petri net was used again to evaluate and verify the performance of the new process.

Hegazy (1999) presented improvements to resource allocation and levelling heuristics, and the genetic algorithm (GA) technique was used to search for near-optimum solutions, considering both aspects simultaneously. In the improved heuristics, random priorities are introduced into selected tasks and their impact on the schedule is monitored. The GA procedure then searches for an optimum set of priorities for a given task that produce shorter project duration and better-levelled resource profiles. One major advantage of the procedure is its simple applicability within commercial project management software systems to improve their performance.

Leu and Yang (1999) proposed a new resource-constrained construction scheduling system, in which a GA-based searching technique was adopted. New GA crossover and mutation operators, UX3 and UM3, were presented. These new operators overcome the drawback of traditional GA operators for sequencing problems. The system can effectively provide the optimal combination of construction duration, resource quantities and minimum project duration under the constraint of limited resources.

Reyck and Herroelen (1999) presented a local search-based solution methodology, which was able to handle many real-life project scheduling characteristics such as time-varying resource requirements and availabilities, activity ready times, due dates and deadlines, activity overlaps, activity start time constraints and other types of temporal constraints.

Hartmann (2001) applied a new genetic algorithm approach to solve project scheduling problems with multiple modes. The genetic encoding is based on a feasible precedence sequence of activities and a mode assignment. After defining the related crossover, mutation, and selection operators, he described a local search extension which was employed to improve the schedules found by the basic genetic algorithm. It is shown that the new genetic algorithm outperforms the other heuristic procedures with regard to a lower average deviation from the optimal makespan.

Hegazy and Wassef (2001) proposed a practical model for the scheduling and cost optimization of repetitive projects. The model objective was to minimize total construction cost comprising direct cost, indirect cost, interruption cost, as well as incentives and liquidated damages. The novelty of this model stems from four main aspects: 1) it is based on full integration of the critical path and the line of balance methodologies, thus considering crew synchronization and work continuity among non-serial activities; 2) it performs time-cost trade-off analysis considering a specified deadline and alternative construction methods with associated time, cost, and crew options; 3) it is developed as a spreadsheet template that is transparent and easy to use; and 4) it utilizes a nontraditional optimization technique, genetic algorithms, to determine the optimum combination of construction methods, number of crews, and interruptions for each repetitive activity.

Lu and Li (2003) developed a resource-activity critical-path method (RACPM), in which 1) the dimension of resources, in addition to activity and time, was highlighted in project scheduling to seamlessly synchronize activity planning and resource planning; 2) the start/finish times and the floats were defined as resource-activity attributes based on the resource-technology combined precedence relationships; and 3) the resource critical issue that had long baffled the construction industry was clarified.

Zhang and Li (2004) developed an optimization methodology, which integrated discrete-event simulation (DES) with a heuristic algorithm, to optimize dynamic resource allocation for construction scheduling. This heuristic algorithm was based on the objective of minimizing project duration and would consider activating multiple activities at the same time based on limited quantities of resources. The optimization was implemented through DES, which could describe complex operational systems through simulation models, without the need to build mathematical models. The proposed methodology provided an alternative to optimize resource flow for scheduling and broadens the application potential of discrete-event simulation in the construction field.

Zhang et al. (2006a) proposed an alternative heuristic method for scheduling repetitive projects, in which resources were limited and activities might be executed with multiple modes of resource demands associated with different durations. Unlike general heuristic methods that separately analyse each competing activity and schedule only one at a time, the proposed heuristic algorithm ranks possible combinations of activities every time and simultaneously schedules all activities in the selected combination leading to minimal project duration. All alternative combinations of activities in consideration of resource constraints, multiple modes and characteristics of the repetitive projects are determined through a permutation tree-based procedure. The heuristic method is implemented based on the corresponding framework.

However, the approaches for project scheduling optimization discussed above fundamentally assume that activities in progress are not allowed to be interrupted. As a result, very little is known about the potential benefits of pre-emption in solving the resource-constrained project scheduling (RCPS) problem (Demeulemeester and Herroelen, 1996). Moreover, the break problem due to off-working time (e.g. night, coffee breaks), which often appears during the overall progress of a construction project, is generally ignored in project scheduling, meaning that the activities in progress cannot be interrupted even in off-working time. These approaches assume that all the activities are non-pre-emptive.

Many attempts to solve the break and pre-emptive scheduling problems have been proposed. Based on CPM, the break problem was studied by Christofides et al. (1981), Fisher and Jaikumar (1981), Baker (1983), Solman (1987), Dumas et al. (1991), and Yang and Chen (2000). None of this research considered resource involvement. Chan and Hao (2002) proposed the scheduling of precast plants using a flow shop sequencing model, which considered a break in off-working time and assumed that each resource was identified with an activity. Zhang et al. (2006b) developed a particle swarm optimization (PSO)-based approach for the resource-constrained project scheduling problem (RCPSB) with project-duration minimization as the objective. It still does not reflect pre-emptive scheduling in consideration of resource-constraints. Zhang et al. (2006c) employed the particle swarm optimization (PSO) method to the pre-emptive scheduling under break and resource-constraints (PSBRC). The method can provide a guide to allocate the resources during the construction progress in consideration of break and resource-constraints. But it does not consider resource sharing and levelling.

In summary, most of the techniques developed to satisfy simulation models focus on special construction processes, for example concreting simulation, repetitive project scheduling, etc. Therefore optimization methods for general construction planning should be further studied. In addition, these methods are still not combined with visualization technologies, and the results from them cannot be visualized.

2.4 Virtual Prototyping Technology and CPMa

Information technology (IT), as well as the environment of the construction industry, is the foundation of applying new management methods or concepts to construction management. This research introduces the IKEA model (a manufacturing management model) to the construction industry in order to improve the construction management of projects. In order to make the application successful, besides the support for the construction industry, advanced information technology is also needed. According to author's pre-research (Huang et al, 2007), virtual prototyping (VP) technology has been identified as being able to effectively and efficiently support this research. Therefore, VP technology is adopted to aid in the application of the IKEA model in construction project management. VP technology is reviewed as follows.

VP is a computer-aided design process concerned with the construction of digital product models (virtual prototypes) and realistic graphical simulations that address the broad issues of physical layout, operational concept, functional specifications, and dynamics analysis under various operating environments (Pratt, 1995; Xiang et al., 2004; Shen et al., 2005). It involves the use of Virtual Reality (VR) and other technologies to create digital prototypes (Gowda et al., 1999). Song et al. (1999)

believed that virtual prototyping refers to the process of simulating the user, product, and the combined interaction by the software through different stages of product design and the quantitative performance analysis of the product.

VP technology has been extensively and successfully applied to the automobile and aerospace fields (Choi, 2004). For instance, an automobile can be fabricated virtually via the VP technology and allows various team members to view the 3D image of the finished products, evaluate the design, and identify the production problems prior to the start of mass production. It has proved to be effective in reducing cost and time, and improving safety and quality. However, the development and application of VP technology in the construction industry (i.e. construction process simulation) has been limited. Sarshar et al. (2004) identified three major industrial barriers to the uptake of VP technology, including cultural and risk issues related to information sharing, fragmentation of business interests and the lack of piloting on real construction projects. Huang et al. (2007) thought that the limited uptake of VP technology was probably because that each construction project was unique in terms of its conditions, requirements, and constraints.

Some research efforts have attempted to apply the VP concept in forming effective dynamic construction project planning and scheduling tools. Boussabaine et al. (1997) suggested VR could be a tool for site layout and planning. Ye et al. (1999) recently recognized the potential benefits of using VR in the planning process by making an experiment. Barsoum et al. (1996) believed that the use of VR model can prompt the project planners to consider all missing details which they fail to think of, for example site safety and site access.

Waly and Thabet (2002) developed the Virtual Construction Environment (VCE) model. It is an integrated virtual planning tool, which allows the project team to undertake rehearsals of major construction processes and to examine various execution strategies in a near reality sense before the real construction work.

Kunz and Fischer (2005) designed the Virtual Design and Construction (VDC) model integrating the product so that contractors can design, construct and operate based on the model. The VDC involves the use of the multidisciplinary performance models of design-construction projects, including the product (i.e. facilities), organization of the project team, and work processes to support explicit and implicit business objectives. It is claimed that the VDC can assist the user to integrate products, which could be buildings or plants. The user can design, construct and operate the product by the VDC. Thus, it enables the improvement of project strategy, the improvement of constructability, a gain of productivity and rapid identification and the solution of time-space conflicts.

CIC (2005) developed the Virtual Facility Prototyping (VFP) for visualizing the building facilities in the construction planning phase. Its focal point is to define methods and design appropriate technologies to create cost effective virtual building prototypes for use in industry and education. More specifically, this research will explore the efficient development and use of VFPs to foster innovation through improved communication of the design and construction process information between project team members including the architects, engineers, contractors, owners and suppliers.

Yerrapathruni et al. (2005) proposed the Immersive Virtual Environment (IVE) method to improve the project planning process by generating and reviewing construction plans in a virtual environment. It is recognized that it can improve project planning development and understanding of the schedule. Constructability can also be reviewed by the IVE. Different construction approaches and strategies can also be tested by this VP technology before commencement of real construction.

In the DIVERCITY project, virtual workspaces, another VP application in the construction industry, was developed. Sarshar et al. (2004) pointed out that the application did not only simulate the 4D models of the project, but also simulated the lighting design, acoustic design, energy consumption, site planning, and safety issues. Therefore it has been identified that VP technology has considerable potential for the design of structural steel, worksite planning and construction project management in general. This research will employ the VP technology customized by the Construction Virtual Prototyping Lab (CVPL) of The Hong Kong Polytechnic University (Huang et al., 2007) to conduct the implementation of the IKEA model in the construction projects management.

2.5 Summary

The definitions and functions of construction project management are analysed and the focus of this research is on the phase from planning/design to construction. For traditional CPMa methods, the functions of critical path method, look-ahead schedule and linear scheduling model are reviewed and their drawbacks are also commented on. These methods are usually used in current construction practice. Due to their limitations, construction reworks often occur. This is also the reason for a lot of research on construction management innovation.

Construction project management innovation mainly focuses on the application of manufacturing management methods in the construction industry, e.g. TQM, SCM, LM, and the innovation of construction process management. On the one hand, from the review, the research and application of these methods in the construction industry is in its infancy due to the big differences between two industries, e.g. mass production in the manufacturing industry. Even so, these applications (especially for LM or LC) offer a great deal of experience for this research in that it also applies a MMM method (the IKEA model) to the construction industry. Some research on new construction process management methods, on the other hand, also provides this research with an important idea about the application of information technology in the construction industry.

As an important IT support tool to this research, virtual prototyping technology arising from the manufacturing industry is also reviewed. This demonstrates that VP technology has an ability to support the design and build process of buildings. Therefore it is believed that VP technology can greatly support this research.

Based on the literature review, the following sections of this thesis will study and present the manufacturing management model (MMM) (i.e. the IKEA model) and study its application in construction project management, including cast-in-situ construction management and precast construction management.

CHAPTER 3 MANUFACTURING MANAGEMENT MODEL AND ITS APPLICABILITY TO CONSTRUCTION PROJECT MANAGEMENT

3.1 Introduction

In order to efficiently apply the manufacturing management model (MMM) to the industry, this chapter analyses the features of the manufacturing industry, presents the MMM (i.e. the IKEA model), discusses the applicability of the IKEA model for the construction industry through a comparison between the two industries and questionnaire survey, and presents the VP technology needed.

3.2 Manufacturing Management Model

3.2.1 Features of the Manufacturing Industry

There are two main production methods in the manufacturing industry: discrete production and process production. Discrete production involves the assembly of the final product using many components (e.g. aircraft, automobile, furniture); process production is the manufacture of the final product directly from raw material (e.g. metallurgy). This research focuses on the application of the discrete production industry and its main features are analysed as follows.

Disassembly and Assembly

A product is made up of a great deal of components which are commonly produced in different sites in order to reduce production costs (e.g. labour costs, raw material costs). This needs the assembly of all these components. Therefore disassembly and assembly is an important characteristic of discrete production, that is, the components are manufactured in different factories (i.e. disassembly) and then integrated together (i.e. assembly). This not only reduces production costs but also makes transportation convenient.

Industrialized Production Line

Although a product consists of many components each component is often produced on an industrialized production line. Production lines make mass production possible and this reduces waste and cost and improves the production efficiency. Industrialized production lines are also an important factor for success in housing industrialization.

Knowledge Management

In the knowledge economics era, knowledge accumulation determines the competiveness of an industry or company. Much attention has been given to knowledge management (KM) in the manufacturing industry. KM not only provides manufacturers with the whole lifecycle information of products, but also provides clients with information related to the use of products. KM reduces the development period of products and improves the competiveness of companies.

Rapid Innovation

The innovation of techniques and management concepts is also an outstanding feature of the manufacturing industry. In the past several decades, the manufacturing industry has achieved dramatic improvements. This is mainly attributed to the application of information technology (e.g. networks, virtual reality) and new management concepts (e.g. TQM, JIT, and SCM) in the industry. These developments provide an important reference for the construction industry.

These characteristics of the manufacturing industry make the industry greatly successful. It is expected that some technologies and management methods from the industry can be used in the construction industry.

Here, the IKEA Group, as a typical representative of the manufacturing industry, is proposed as a foundation for implementing the study of the application of MMM in the construction industry. As the world's largest (and arguably most successful) furniture retailer, the IKEA Group and its methods (i.e. the IKEA model) have been studied by many researchers from several perspectives and its smart logistics system (Klevas, 2005), revolutionary strategy (Barthelemy, 2006) and management system (Weisbord and Jandoff, 2005) have inspired other industry sectors. The following section will propose and analyse the IKEA model.

3.2.2 IKEA Model

The IKEA Group is a privately-held, international home products retailer that sells competitive products, including furniture, accessories, bathrooms and kitchens at retail stores around the world. It became famous for the fact that the customers have to assemble many of the products. IKEA was founded in 1943 by Ingvar Kamprad in Sweden and it is owned by a Dutch-registered foundation controlled by the Kamprad family. IKEA is an acronym comprising the initials of the founder's name (Ingvar Kamprad), the farm where he grew up (Elmtaryd) and home village (Agunnaryd) (Wikipedia, 2008).

The essence of the IKEA spirit is “offering a wide range of well-designed, functional home furnishing products at prices that are so low that as many people as possible will be able to afford them” (Mather, 1992). As mentioned above, in the manufacturing industry, the disassembly and assembly of a product are two basic activities which determine its cost. The disassembly of a product is a precondition of standardized production, and assembly of standardized parts is closely related to logistics and marketing. Costs are reduced by controlling these two basic activities. To do this, IKEA extends the traditional principle of “DFM, or design for manufacturability” to “DFL, or design for logistics” (Mather, 1992), by considering both the function and manufacturability, and the convenience of packaging, transporting and assembling of the product. The IKEA model also incorporates customer self-service, which means that customers are themselves responsible for locating, collecting, transporting and assembling the purchased furniture. IKEA’s combination of careful design disassembly, collaboration with the cheapest suppliers, and customer self-service, results in substantial cost savings (Barthelemy, 2006). These are passed on to customers in the form of competitive prices which, together with the consequent high sales volumes, gradually increases the company’s profitability.

To support customer self-service, IKEA provides an attractive catalogue and set of 3D assembly instructions (e.g. a 3D instruction for a table shown in Figure 3.1 and Figure 3.2). The catalogue contains abundant information, with the product name, price, size, composition, possible usage and alternative decoration style and even an introduction to the designer. It also serves as a type of functional advertisement to attract customer attention and induce consumption through its high-quality Scandinavian design style. Customers obtain all the information required for product selection and purchase without the need for sales personnel. Likewise, the vivid 3D instruction leaflet clearly demonstrates the assembly method and sequence – obviating the need for professional input.

Figure 3.1 An IKEA dining table

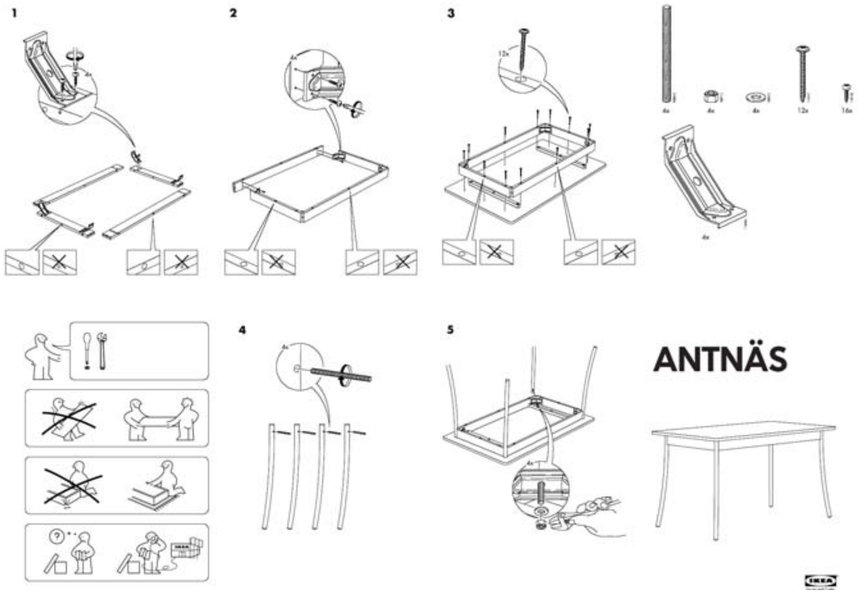


Figure 3.2 The 3D assembly instruction for the IKEA dining table

Source: IKEA Website (www.ikea.com)

Figure 3.3 illustrates the concept of the IKEA model, the main benefits of which are as follows:

- *Optimizing the process from design to ultimate consumers*. As the consequence of DFL, the simplicity of assembling becomes one of the significant aspects of design. Unassembled furniture also enables flat packaging, which reduces the logistics costs involved and allows customers to provide their own transportation.

- *Simplifying management activities*. The management activities and personnel required for marketing, selling, delivering and assembling are minimised, requiring only a simple management organization which helps to form the IKEA's flat organizational structure.

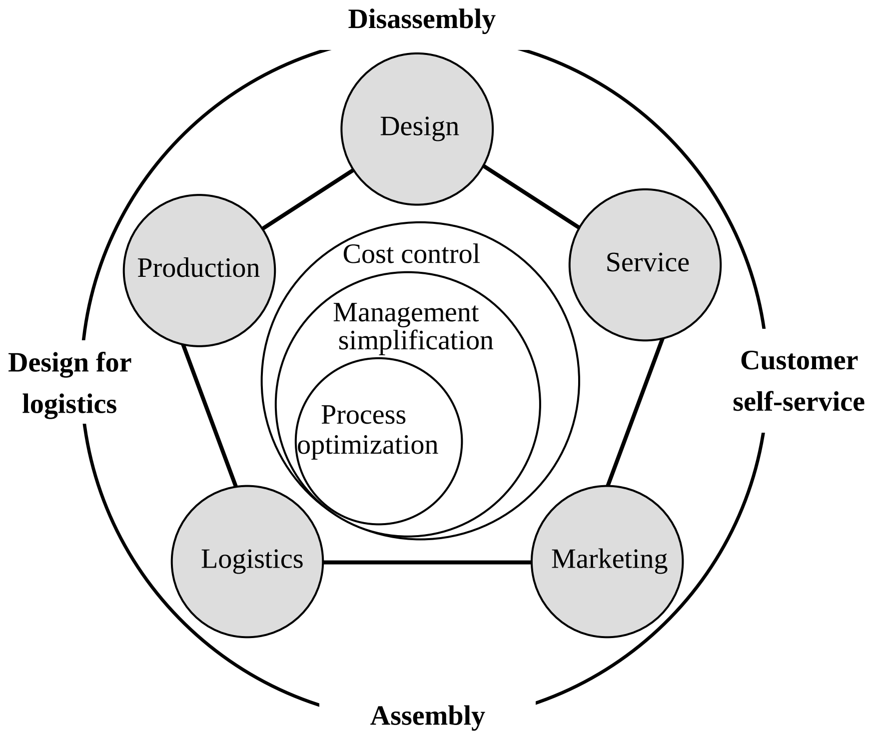


Figure 3.3 The IKEA model

In recent times, the IKEA model has come to denote a broader and ideological form, often associated with popular culture in a negative sense, with its cheap and quick, low quality, disposable image. Its do-it-yourself philosophy (Wall, 1999), for example, has been identified with “politics where you make the wished-for changes yourself … a political model of direct action, where the citizen herself is equipped with accessible tools to affect desired effects by herself” (Vinthagen, 2006). Likewise, the 'IKEA model of medical advance', in doing “the basic science in the laboratory and self-assemble in the clinic”, is said to be damaging clinic advance (Rees, 2001). Even further education (FE) has been said to be suffering from an IKEA mentality (Scaife, 2004). From a production process viewpoint, however, the IKEA model clearly has much in its favour and the next section considers its feasibility for use in construction project management.

3.3 MMM’s Applicability for Construction Project Management

The MMM’s applicability for construction project management is analysed via a questionnaire survey and a comparison between the manufacturing industry and the construction industry.

3.3.1 Survey of MMM’s Applicability for CPMa

The aim of the questionnaire survey is to check the feasibility of applying the IKEA model to construction project management from the point of view of researchers and practitioners in the construction industry. The objects of the survey, therefore, are professionals (e.g. project managers, researchers, etc) in the field of construction project management. The questionnaire is designed based on the IKEA model as shown in Appendix I. Note that the questionnaire has been reviewed and confirmed by experts in construction management and therefore it is reasonable and can reflect whether or not it is feasible to apply the MMM to construction project management.

A questionnaire survey was conducted in 2007 and its sample includes 40 researchers and 40 practitioners in Hong Kong and Mainland China. The valid response is 27, i.e. 15 researchers and 12 practitioners, almost all of who have participated in construction project management for more than five years and therefore have much experience in construction management. As they are all professionals in construction project management, the reliability of the survey results is very high (i.e. Cronbach's Alpha equals 0.78 which shows high internal consistency reliability).

The questionnaires are statistically analysed and a summary of the results is shown in Figure 3.4, where a Likert Five-point Scale is employed to quantify and measure respondents' attitudes toward the feasibility of applying the IKEA model to construction project management. The range from one to five represents the degree of agreement from weakness to strength, i.e. one denotes very weak, three denotes medium and five denotes very strong. If the value is over or equal to three, it means that it is feasible to apply the IKEA model to the construction industry; and vice versa.

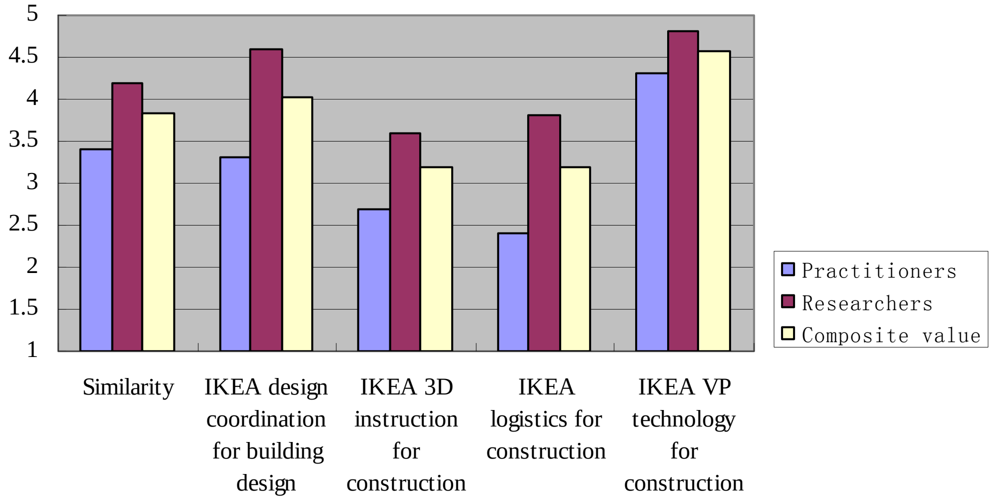


Figure 3.4 The survey results for the feasibility of the IKEA model to CPMa

It can be seen from Figure 3.4 that:

1) The perspectives of practitioners and researchers are different, and for every item

the value from practitioners is less than the one from researchers, especially for the *IKEA logistics for construction*. This shows that researchers are more confident in the application of the IKEA model in the construction industry than practitioners. The main reason identified for this is that researchers' understandings of the IKEA production and management method are different from that of practitioners and, perhaps, researchers have a much clearer understanding of the IKEA model than practitioners.

2) The composite value of each item is over three and this means the IKEA model is applicable for construction project management from the point of view of respondents. Although the value from practitioners for the *IKEA 3D instruction for construction* and the *IKEA logistics for construction* is less than three, the composite value is still more than three. For the *IKEA design for building* and the *IKEA VP technology for construction*, the composite value is over four and this means that both of them are very feasible.

Additionally, from the questionnaire survey, it is found that 1) some problems often happen in construction project management, such as time and cost overruns, and safety and quality problems, considered by above 95%; 2) although responses for their reasons from different respondents, such as clients, architects, contractors, and so on, are different, 78% of respondents thinks these problem are mainly caused by design problems and inappropriate construction plan and management methods; and 3) management and technology innovation is highly expected to solve these problems, especially by contractors and clients, specifically the innovation of communication means, construction process planning and management, and design tools is needed. To some extent, these are the reasons for why this research is conduced.

Therefore, to offer a support to current construction project management, the application of the IKEA model in the construction industry may be tried. In order to ensure this, the subsequent section discusses the feasibility of MMM for construction project management from another viewpoint, i.e. comparing the manufacturing industry with the construction industry.

3.3.2 Comparison between the Manufacturing Industry and the Construction Industry

The manufacturing industry (i.e. IKEA) and the construction industry are compared on the basis of their respective production processes. Process management in the construction and furniture industries faces similar problems: both industries are traditionally of a bespoke nature and are highly fragmented; furniture manufacturers need to deal with various suppliers while construction firms work with a range of subcontractors and consultants; cost, quality, and assembly ability/buildability are important concerns for both. Table 3.1 summarises the major similarities involved.

Table 3.1 The similarities between construction process and IKEA's manufacturing process

Item	Construction project	IKEA furniture
Industry trait	Fragmental	Fragmental
Process	Project-oriented, customized	Customer-oriented, cost-driven
Partnership	Complex, teamwork	Complex, collaborated with suppliers
Objective	Low cost, high quality, safe, timely	Low cost, high quality, in time

These similarities indicate that it may be beneficial for the construction industry to adopt some of the furniture industry's more modern practices as exemplified by the IKEA model of optimizing the project processes involved, simplifying the management tasks required and using VP technology (Mather, 1992).

The IKEA model is especially applicable for precast construction projects. The ideas underpinning precast construction originate from the manufacturing industry, that is, buildings are expected to be built in the same way as a product is produced. Precast construction has a lot of similarities to the production of the manufacturing industry. Table 3.2 shows the main similarities between precast buildings and IKEA furniture. These similarities are key to applying the IKEA model to precast construction. In theory at least, the IKEA model is more suitable for precast construction projects that cast-in-situ projects.

Table 3.2 Main similarities between precast building and IKEA furniture

Item	Component type	Production means of component	Production site of component	Assembly of component
IKEA furniture	Prefabricated	Standardized production line	Off site	On site
Precast building	Precast or prefabricated (many) Cast-in-situ (few)	Customized production line	Off site (usually) or on site	On site

Some differences between IKEA furniture and construction projects need to be taken into consideration in order to succeed in applying the IKEA model to construction project management.

1) Construction processes are irreversible. Unlike furniture, which can be rebuilt when serious problems occur, the construction process cannot be repeated for the same project. Therefore the idea of “try before build” is important to construction and this relies strongly on VP technology.

2) Whether precast construction or cast-in-situ construction, construction processes involve many resources (e.g. workers, materials and equipment) on site. These resources need to be supplied on time to the right location under the conditions of a safe environment. It is difficult to control this in current construction management. The use of VP technology can make this possible before the commencement of actual construction.

3) Precast components of precast building are usually bigger than those of furniture and they need detailed and clear instructions for their installation and transportation. Tests related to transportation and installation should be conducted in advance and this is also supported by VP technology.

4) Precast components are often more expensive than those of furniture and errors

from design or production would make cost increase rapidly. VP technology is needed to avoid these problems.

VP technology, on the other hand, which arises from the manufacturing industry, has been identified as having considerable potential for the design of structural steelwork (Slaughter and Eraso, 1997), site planning (Tawfik and Fernando, 2001) and construction project management in general (e.g. Sarshar et al., 2004; Hobbs and Dawood, 1999; Riese, 2006). It is believed that the effect of the above-mentioned differences on the application of the IKEA model to precast construction can be eliminated though the employment of VP technology.

According to the above analysis, it is demonstrated that the IKEA model is applicable for construction project management, at least in theory and this provides a theoretical foundation for this research. Since this requires the support of VP technology, the next section will customize an appropriate VP technology.

3.4 Provision of Virtual Prototyping Technology

The VP technology adopted in this study comprises a set of computer software developed by the Construction Virtual Prototyping Lab (CVPL) at the Hong Kong Polytechnic University (see www.cvptl.com for more information). Through customizing two software systems, CATIA V5© and DELMIA V5© of the

DASSAULT SYSTEMS, and adding construction specific functions, the virtual prototyping technology provides a digital mock-up of construction processes and activities. It extends current technologies, such as 4D CAD, by providing the capacity to simulate not only three dimensions and time (4D), but all important dimensions (ND) of a construction project such as safety and resources (including human, devices, etc.).

Specifically, the current 4D model does not convey all the information required to evaluate the schedule. Building components and construction equipment are usually modelled as the 3D images and linked with the schedule. These 4D CAD systems lack construction-specific components such as scaffolding and other temporary works integrated in the 3D model. Such 4D models do not show the space needs and corresponding potential congestion of temporary works (Koo and Fischer, 2000; Chau et al., 2005). However, temporary works are a critical element of the overall construction plan. Failure in planning appropriate temporary structures affects safety, quality, and productivity adversely (Chini and Genauer, 1997). A detailed comparison of VP and other similar technologies is available in (Huang et al., 2007)

The use of VP enables a ‘try before build’ simulation. To validate the assembly ability of its products, the assembling process of an IKEA product needs to be tested in a VP system to ensure that customers can conveniently ‘build’ the product ‘on-site’. Similarly, VP technology can be adapted and applied to improve the buildability of construction projects. The application of VP technology in the construction industry can fulfill the function of checking design errors efficiently, modifying these rapidly, and then simulating the construction process in a virtual environment so as to present a clear and easily-operated 3D construction instruction (Huang et al., 2007). Therefore, VP technology can provide a virtual experimentation platform for the implementation of process optimization and for management simplification during the construction process.

3.5 Summary

A manufacturing management model, i.e. the IKEA model IKEA, is proposed after the selection and analysis of IKEA, as a typical representative of the manufacturing industry. The MMM's applicability for the construction project management is discussed and demonstrated through a questionnaire survey from professionals in the field of construction management and a comparison analysis between the manufacturing industry and the construction industry.

As an important IT-support tool to the application of the IKEA model in CPMa, the VP technology is provided by the CVPL of the Hong Kong Polytechnic University. It breaks through the limitations of traditional 4D simulation tools and realizes ND-based simulation. It is believed that the VP technology can aid in the use of the IKEA model in CPMa.

The subsequent sections further elaborate how construction processes can be optimized and management activities simplified with the VP-based IKEA (or MMM) approach. Due to the differences between cast-in-situ construction management and precast construction management, the application of the VP-based IKEA approach to each of them will be discussed.

CHAPTER 4 USING THE VP-BASED IKEA MODEL TO IMPROVE CAST-IN-SITU CONSTRUCTION PROJECT MANAGEMENT

4.1 Introduction

As was analysed above, it may be beneficial for the construction industry to adopt some of the manufacturing industry's more modern practices as exemplified by the IKEA model of optimizing the project processes involved, simplifying the management tasks required and using VP technology (Mather, 1992). This chapter will propose the process of the application of the VP-based IKEA model in cast-in-situ construction project management.

4.2 Overview of the Application of the VP-based IKEA Model in Cast-in-situ CPMa

Cast-in-situ construction is the conventional construction method, in which buildings are built through casting on site. Time and cost overruns become normal and quality and safety cannot be assured due to construction uncertainties. The application of the VP-based IKEA model to cast-in-situ construction project management mainly focuses on the solutions of these problems through two aspects, i.e. the *optimization of construction processes* and the *simplification of management activities*.

4.2.1 Optimization of Construction Processes

Construction processes are characterised by their uncertainty and complexity, and many problems are caused by design errors and a mismatch of planned and actually needed resources. The complexity of the construction product makes design errors inevitable and difficult to identify prior to the project commencement. Construction process control, on the other hand, seldom provides sufficiently timely coordination of labour, material and equipment from different providers, and mismatches occur frequently. It is well known that design errors and mismatches of resources generate reworking, change orders and disturbance of construction plans and schedules, thereby increasing costs (Park and Pena-Mora, 2003). Therefore, the objective of optimizing the construction process management is to reduce design errors and provide a reasonable construction sequence prior to the commencement of construction works.

4.2.2 Simplification of Management Activities

Empirical data indicates that construction costs increase exponentially with the increasing degree of complexity and scale of a project (Love et al., 1999). Larger and more complex projects involve more management activities and hence need more personnel to prevent, control and solve problems such as design changes, resource mismatches and conflicts among project participants. Simplifying management activities through eliminating non-value-adding processes and/or amalgamating activities enables the reduction of management personnel and costs.

4.3 Optimization of Construction Processes

The optimization of the construction processes focuses on the elimination of non-value-added and unnecessary cost-adding activities, including change orders for design errors, reworking caused by inappropriate planning and inappropriate operations, information misunderstandings among construction partners, and inefficiency due to a lack of skilled crafts people.

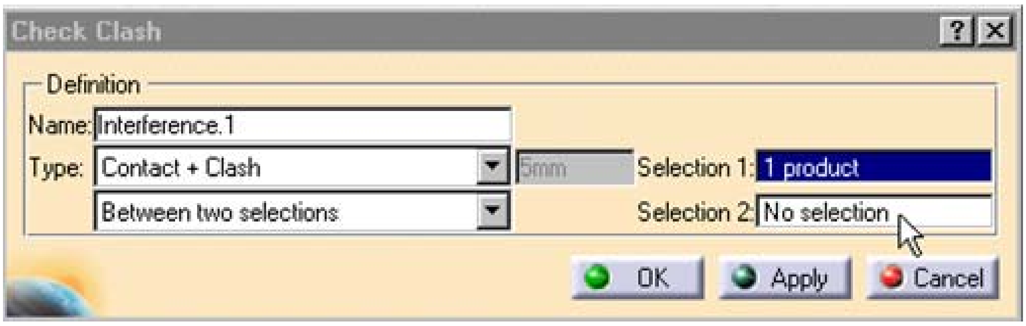
Through constructing 3D models from 2D drawings of a construction project, many design errors such as missing or inconsistent dimensions can be easily identified based on the concept of the IKEA model. In addition, the collision detection technique embedded in the VP technology will help identify conflicts of components.

Specifically, the optimization of construction processes is obtained from the following five perspectives.

4.3.1 Design Check and Constructability Evaluation

Design is a process to translate the owner’s desire to physical facilities. Typically, architects and engineers from different disciplines produce separate designs which contain errors, such as dimensional inconsistencies and missing information, which directly lead to rework (Love et al., 2004). Prior to the availability of VP technology, it was not possible to test the completeness and correctness of design as this required a physical mock-up, which was both costly and risky to produce (Akintoye et al., 2000) and sometimes could not be produced due to the complexities of construction projects. Design errors were then identified and solved through remedial work on site, which would lead to time and cost waste. This is a big difference from the furniture industry which may not need VP technology as a physical mock-up can be produced to check for design errors.

The application of VP technology requires collaboratively developing 3D models (main model or digital mock-up) of the project from 2D drawings. This process enables many design errors to be detected automatically and the construction sequence can be simulated and improved. Figure 4.1 shows the interface of automatically checking for design errors in construction projects using the VP technology provided by CVPL. The type of clash checking can be customized and objects for checking can be selected to satisfy your requirements.



Check Clash

Definition

Name: Interference.1

Type: Contact + Clash

5mm

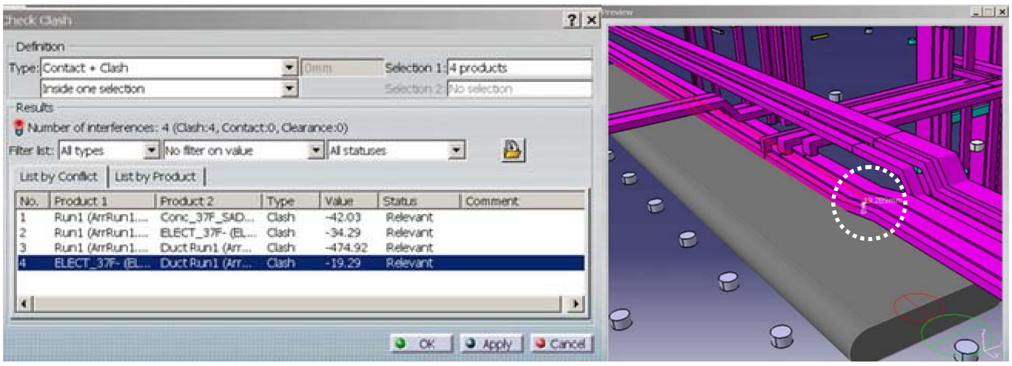
Between two selections

Selection 1: 1 product

Selection 2: No selection

Figure 4.1 Design errors checking interface for construction projects

VP technology can be used to check for any clashes among any components of a construction project, for example architecture, structure, and building services (BS). The design errors detected are listed with relevant 3D mode. As an example, Figure 4.2 demonstrates four design errors between BS found as a result of checking with VP technology. When selecting a design error, its 3D representation is shown in the right window. It can be seen that the design error shows a collision between two ducts of the air conditioning system. Additionally, a checking report can also be created automatically.



Type: Contact + Clash
Inside one selection
0mm
Selection 1: 4 products
Selection 2: No selection

Number of interferences: 4 (Clash:4, Contact:0, Clearance:0)
Filter list: All types | No filter on value | All statuses

No.	Product 1	Product 2	Type	Value	Status	Comment
1	Run1 (ArrRun1....	Conc_37F_SAD...	Clash	-42.03	Relevant	
2	Run1 (ArrRun1....	ELECT_37F- (EL...	Clash	-34.29	Relevant	
3	Run1 (ArrRun1....	Duct Run1 (Arr...	Clash	-474.92	Relevant	
4	ELECT_37F- (EL...	Duct Run1 (Arr...	Clash	-19.29	Relevant	

Figure 4.2 Design errors checking process for BS

4.3.2 Translating the Construction Schedule into 3D Step-by-Step Instructions

Through simulating and improving the construction sequence, the construction schedule can be translated into a series of 3D step-by-step instructions (just like 3D assembly instruction of the IKEA furniture) that are easier for project participants to understand and follow. Traditionally, project managers use bulky construction documents - typically including 2D drawings and written specifications and manuals -

to manage projects. A major task of project managers is to understand these documents and derive executable actions from them. However, understanding the documents is never a trivial task as it is both time-consuming and easy to make mistakes. To translate construction documents into executable actions, project managers need to mentally construct construction sequences based on their understanding of the documents. Again, this often leads to misinterpretations, risks and uncertainties. The provision of 3D step-by-step construction sequences to project managers should substantially relieve project managers of this task and trim down the size of project management teams.

4.3.3 Identification of Unsafe Zones and Quality Problems

Quality and safety are critical objectives to project management as they can reduce project time and costs. Project managers need to ensure that all materials, equipment and operations achieve the required quality in a safe project environment. The traditional approach to quality and safety management is mainly reactive: waiting for problems to occur and then taking on-site remedial actions. This practice is inefficient and costly (Akintoye et al., 2000). From the concept of the IKEA model, the use of VP technology makes it possible to identify quality problems and unsafe zones in advance. By navigating through virtual construction sites, quality problems and unsafe zones can be pre-determined and detected by quality control engineers and safety officers. These include locations for possible human-machine interactions (e.g.

see Figure 4.3), missing or incomplete safety nets, and narrow or insufficient workspaces. Meanwhile, structure analysis can also be conducted to pre-detect locations for possible structure problems. In other words, the use of VP technology can transform construction project management from a reactive to proactive management style.

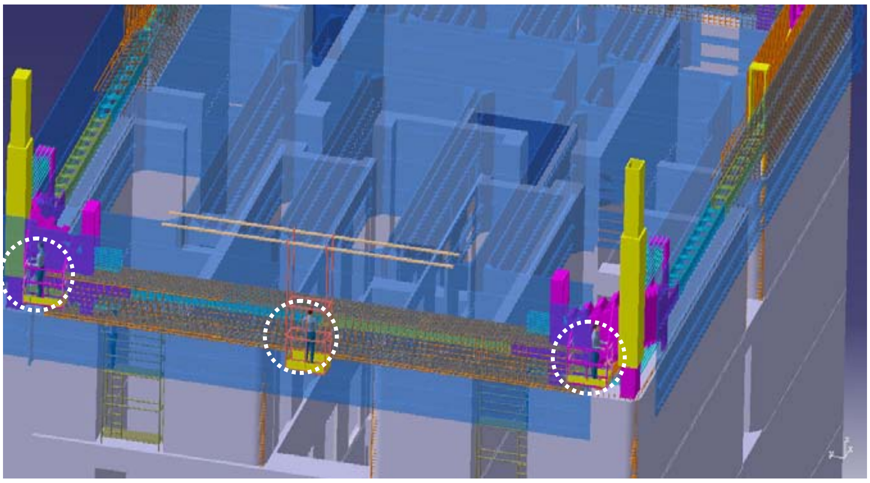


Figure 4.3 Detection of unsafe zones

4.3.4 Effective Communication Platform for All Project Participants

The current practice is for the general contractor to be responsible for process planning, control and coordination. However, there are often inconsistencies and conflicts in the project information generated by the various parties involved in projects. To address this, a collaboration platform as seen in the IKEA model is needed. VP technology represents project information in virtually realistic forms and provides a focal point to host and exchange project information. Figure 4.4 shows the VP-based collaboration platform of a construction project, including structure and architecture components and BS. Project participants can therefore obtain direct and unequivocal information simultaneously. This thus eliminates the bottleneck problem in communication among project participants (Elliman and Orange, 2000).

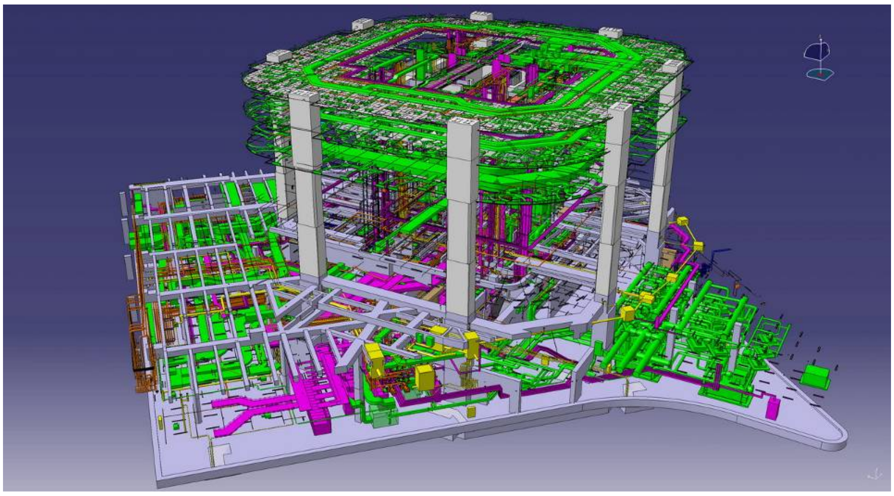


Figure 4.4 VP-based collaboration platform of a construction project

4.3.5 Construction Knowledge Management

Construction process simulation can provide a visual platform to demonstrate complicated construction techniques and procedures to craft workers. Using VP technology, construction techniques can be vividly and visually demonstrated and recorded. The recorded visual information captures construction knowledge in a direct and information-rich format that is easy to understand and follow. The accumulation of visual information in this format (just like the knowledge base of the IKEA furniture) may be re-used in future projects (especially for precast buildings) and for educational purposes. Moreover, design knowledge can also be stored and reused for future projects. Figure 4.5 shows design data for some BS components.

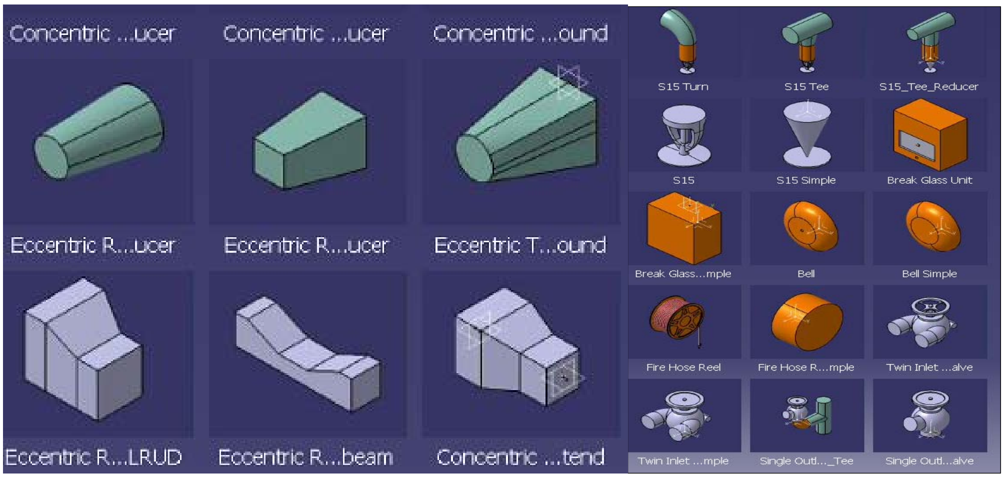


Figure 4.5 Knowledge management for design of construction projects

4.4 Simplification of Management Activities

As stated previously, the management cost of a construction project can amount to 13% of the total cost, while in an IKEA assembly process the management cost is nil. The reason for IKEA's achievement of zero management costs is that its assembly process is guided by a step-by-step 3D instruction which is easy to understand, unlike a construction plan and schedule which is often difficult to follow. In order to reduce the management cost of a construction project, this study applies VP technology to simulate construction processes. The simulated processes can be presented as step-by-step instructions which are easily followed by on-site operatives. Because of this, on-site management personnel can be reduced and the associated management activities simplified.

The application of VP technology to the construction process creates a new project participant, the process simulator, in project delivery. With this new participant, the functions and roles of existing project participants can be re-arranged and the construction process simplified. Specifically, the follow aspects of the construction process can be changed.

4.4.1 Simplification of the Document Submission Process

Design and planning documents are exchanged among project participants. For example, many documents, including design drawings, product data and samples need to be submitted by subcontractors to the architect, engineer and general contractor for approval. This is important because it is closely related to the quality, schedule and even the success of the overall project. However, the submission and approval process is complex and time consuming (see Figure 4.6) because:

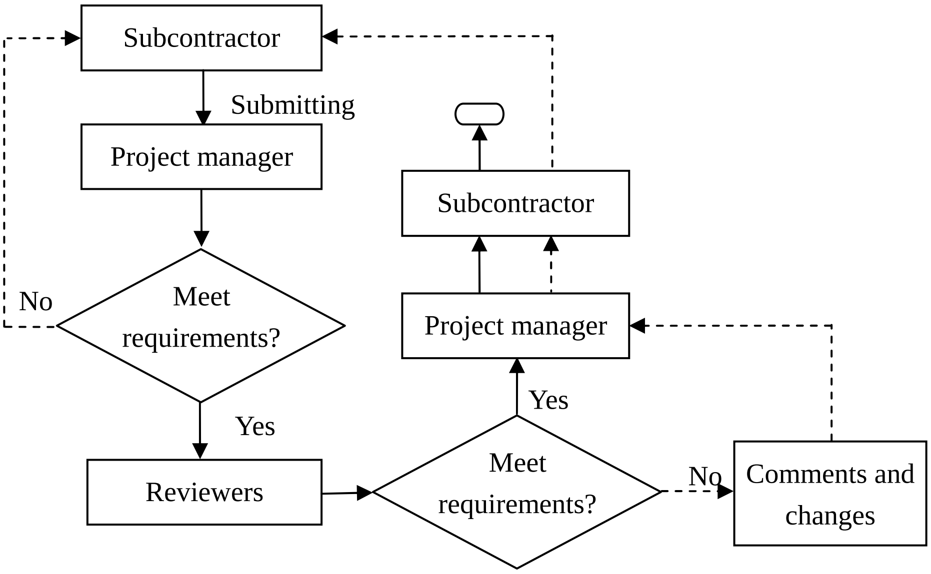


Figure 4.6 Traditional document submission processes

- project information is prepared in various formats such as 2D drawings, tables and texts, which may lead to misunderstandings among project participants; and
- comments or changes cannot be included in the submitted document.

Using VP technology, the submission process can be improved as illustrated in Figure 4.7. Here, the submitted documents are simulated and translated into visual models and sequences that inform which may feasibility be evaluated. Design errors from 2D drawings are revealed and detected automatically and the impact of alternative construction methods can also be analyzed.

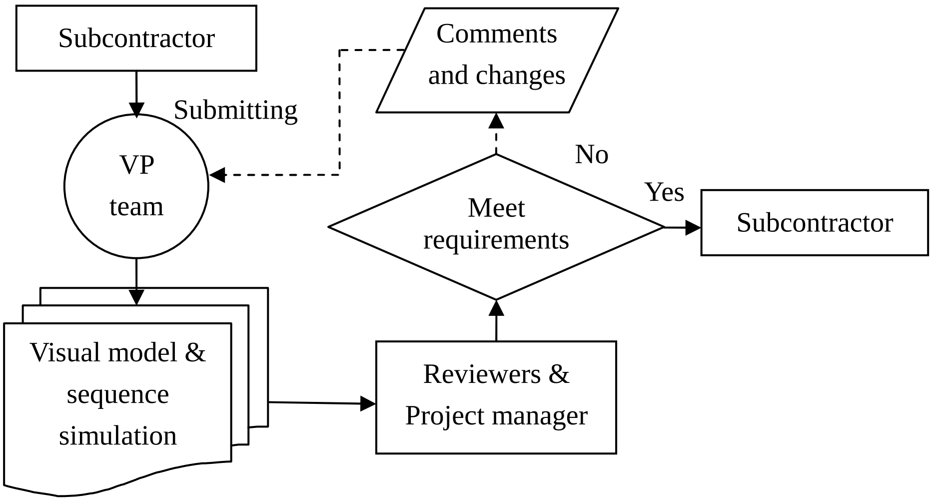


Figure 4.7 VP-based document submission processes

4.4.2 Re-arrangement of the Roles and Responsibilities of Project Managers

The application of VP technology in construction process management transforms project management from a reactive and remedial approach to a proactive approach.

Generally, project management can be divided into five phases (Park and Pena-Mora, 2003): project initiating, project planning, project executing, project controlling and project closing, as shown in Figure 4.8.

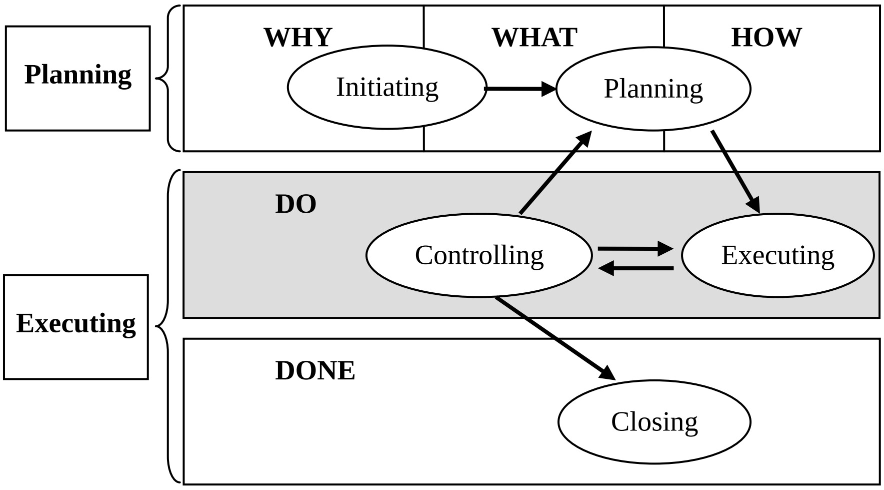


Figure 4.8 The construction project management process

Existing planning tools, such as the critical path method (CPM) and Gantt charts, can only allow planners to represent time, activities and their interdependences, and resources of a project, whereas important information, such as site layout and the dynamic spatial relationships between the plant, materials and operatives, cannot be represented. This directly leads to inappropriate and un-executable construction plans, and disputes and rework arising. This also explains the existence of multiple ‘executing’ and ‘controlling’ phases, as indicated in Figure 4.8.

As a powerful construction planning technique, VP can be used to prepare and verify the feasibility of the design and construction plan. In a VP environment, the planner is provided with a virtual construction site with all the necessary information needed to develop a realistic construction plan. Within this environment, planners can conduct ‘what-if’ analyses to ensure the feasibility and constructability of all details of the construction plan. After this process, it is unlikely that rework due to incorrect executing will occur, rework due to inappropriate planning will be reduced to the utmost extent, and therefore ‘executing’ and ‘controlling’ become unambiguous and non-repetitive, as shown in Figure 4.9. Thus the management personnel and costs configured to these two phases can be reduced.

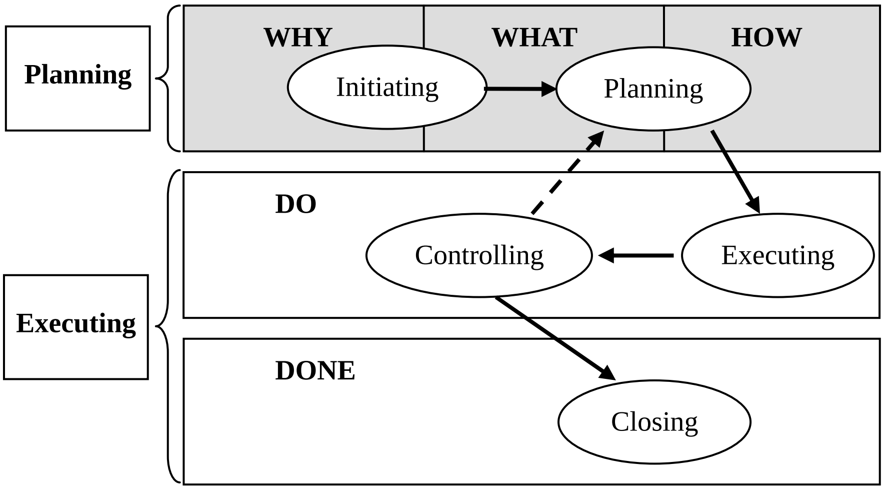


Figure 4.9 Construction project management process based on VP

4.5 Summary

As a conventional construction method, cast-in-situ construction is used widely. For a long time in cast-in-situ construction, many problems (e.g. time delays) have consistently occurred and therefore these problems have been regarded as normal features of construction projects. This has led to low productivity in the construction industry. In order to reverse this, efforts to apply the VP-based IKEA model to cast-in-situ construction are made, aiming to improve the *optimization of construction processes* and the *simplification of management activities*.

For the optimization of construction processes, it is proposed that the checking for design errors, the constructability evaluation, the visualization of the construction schedule, and the identification of unsafe zones and quality problems are conducted using the VP technology to reduce construction uncertainties and improve construction quality. VP technology also provides an efficient communication platform for all parties in a construction project to realize design coordination, and a construction knowledge management platform for owners/contractors to aid in future projects and in the training of workers. For the simplification of management activities, on the other hand, the document submission process is simplified using VP technology, and the rearrangement of the project management team is allowed through cutting down or combining roles due to the elimination or reduction of construction uncertainties, thus saving time and reducing management costs.

Owing to the high similarities of precast buildings and IKEA furniture, it is believed that the VP-based IKEA model is more applicable to precast construction than cast-in-situ construction. The next chapter will elaborate how to apply the model to precast construction project management.

CHAPTER 5 USING THE VP-BASED IKEA MODEL TO IMPROVE PRECAST CONSTRUCTION PROJECT MANAGEMENT

5.1 Introduction

Precast construction technology has become more popular in the world-wide construction industry due to its benefits (e.g. better quality). However, these benefits do not play enough of a role in real-life construction projects. Owing to many similarities between precast construction and IKEA production, this chapter will present how to conduct the IKEA model in precast construction in order to realize the original aims of precast construction.

5.2 Overview of the Application of the VP-based IKEA Model in Precast CPMa

Much attention has been paid to precast or prefabrication construction by many countries in the past several decades due to its advantages, which include time and cost savings (Frondistou-Yannas et al., 1976; Tucker and Dryden, 1977), high quality (Seckin and Fu, 1990; Soubra et al., 1991, 1993; Korkmaz and Tankut, 2005), high safety (Elliott, 2002), resource levelling (Leu and Hwang, 2002), etc. These improve the efficiency and productivity of the construction industry (Chan and Poh, 2000;

Chan and Hu, 2001). For example, in the United Kingdom, precast concrete construction was extensively developed in the 1950s to satisfy the high demand for housing due to destruction during World War II (Finnimore, 1989); Singapore's Housing Development Board (HDB) introduced precast concrete technology into Singapore in the 1980s in order to meet its Fifth Building Programme target while checking construction costs, reducing labour and improving productivity and quality of workmanship (Wong and Yeh, 1985); in the early 1980s, Hong Kong began to apply the precast or prefabrication technique to public housing and made rapid progress in the mid-1980s due to the rapid increases in wage and the shortage of labour. Therefore, the development of precast construction has an important influence on the construction industry.

Although some successes have been made in the cases mentioned above, some problems remain, e.g. time and cost overruns (Wong and Yeh, 1985). Precast components are usually designed, produced and assembled in different sites by various parties and often some design errors are found when installing them. However, after producing precast components, especially precast concrete components, it is almost impossible to modify them. This leads to reworks, meaning that time is often delayed and cost is added. Sometimes safety is also a serious problem when installing precast components. Some precast and prefabricated components are huge and heavy and therefore it is complex to install them. If the installation programme or sequence is not very clear or reasonable, workers cannot understand them well. When installing these components, accidents often occur, for example collisions between components, or even with workers. This often happens in precast construction and this is opposite to the target of precast or prefabrication construction, viz. time and cost savings, etc. Unfortunately these problems have not yet been solved though advanced methods or technologies. All that can be done is to reduce the problems by employing some skilled workers and being careful during critical points.

As analysed above, and similar to precast or prefabrication construction, almost all production in the manufacturing industry is conducted via the design-production-assembly way on different sites. But it is, overall, a very efficient process comparable to precast construction, and IKEA furniture is a typical example and is very similar to precast construction. This makes it possible to use the IKEA model in precast construction to solve some of the problems in precast construction. The application of the IKEA model in precast construction will be discussed by following the concept of the IKEA model, i.e. *design-production-transportation optimization* (DFM and DFL) and *assembly optimization*, to improve precast construction management.

5.2.1 Design-Production-Transportation Optimization

Precast construction involves a great deal of precast components and the design of precast components affects not only installation but also production and transportation. Many reworks are done in the production, transportation, and installation phases, especially for complex precast construction projects, often due to design problems. From the concept of the IKEA model, design for manufacturability (DFM) or design for logistics (DFL) can optimize the design-production-transportation process using VP technology.

5.2.2 Assembly Optimization

The installation of precast components needs to be arranged reasonably to ensure the trade-off between the construction schedule and the supply of precast components. This usually relies on the project managers’ experiences. Although some project managers have rich experience of project management, it is difficult for them to take into consideration the whole process in detail using only the current management methods (e.g. master programme). Of course common workers find it more difficult to understand. Therefore, problems often occur during precast construction, especially in complex projects. The aim of assembly optimization is to reduce these risks during installation through the application of the VP-based IKEA model.

5.3 Design-Production-Transportation Optimization

5.3.1 Design Optimization

As we know, the design of a building comprises architecture, structure, building services (BS), etc. Each of them is done by different parties and after being finished they are assembled. Since different participants seldom communicate with each other besides exchanges of some main shop drawings, when these components are installed some collisions occur. This leads to rework, causing cost and time waste. Especially for precast components, after being finished they cannot be modified and the correction of any design errors related to components leads to dramatic increase in cost and time. Furthermore, precast design has a direct influence on production. Unreasonable design often makes it difficult to produce precast components. Also, due to usual off-site production of precast components, they must be transported to the construction site. Rework also increases transportation costs. Therefore these problems should be solved during design and not extended to the construction phase.

The idea of “design coordination” (DFM and DFL) in the IKEA model is employed to conduct the task mentioned above. VP technology is adopted to provide a collaborative platform for all participants, such as architects, structure engineers, BS engineers, owners, contractors, and so on. That is, all participants use VP technology to conduct the design and to update the design in real time in a 3D main model (termed here digital mock-up) (see Figure 5.1), which is built in a virtual environment. Due to the vivid 3D main model and the function of design error auto-check in VP technology, it is clear and easy for each party to find problems existing in the design e.g. design errors, collisions, constructability, etc. They can then discuss and solve them conveniently via real-time communication, as provided by VP technology. This saves lots of time and cost and ensures the quality of precast components.

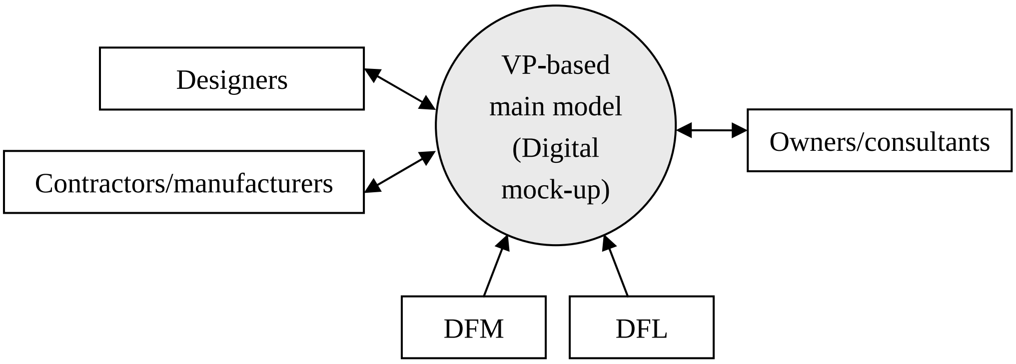


Figure 5.1 Design coordination for precast construction

The idea of DFL, on the other hand, is also followed in the design coordination to reduce transportation problems. Due to the large volume or non-typical shapes of some precast components, the feasibility of their transportation is another focus for designers. Based on the idea of design coordination, the design of precast components can be tested in advance using VP technology to demonstrate the feasibility of transporting precast components, not only for transportation tools but for the space layout of construction sites. This can help determine the appropriate size of precast components. Transportation problems are found and solved ahead of production.

Specifically, as VP technology is not yet employed widely in the design of buildings, a third party (process modeller, e.g. CVPL) has appeared in practice to satisfy the current demand (see Figure 5.2). The third party works with all other parties, uses VP technology to transfer all 2D drawings provided by different design parties to 3D models, conducts the analysis related to design, and offers some suggestions.

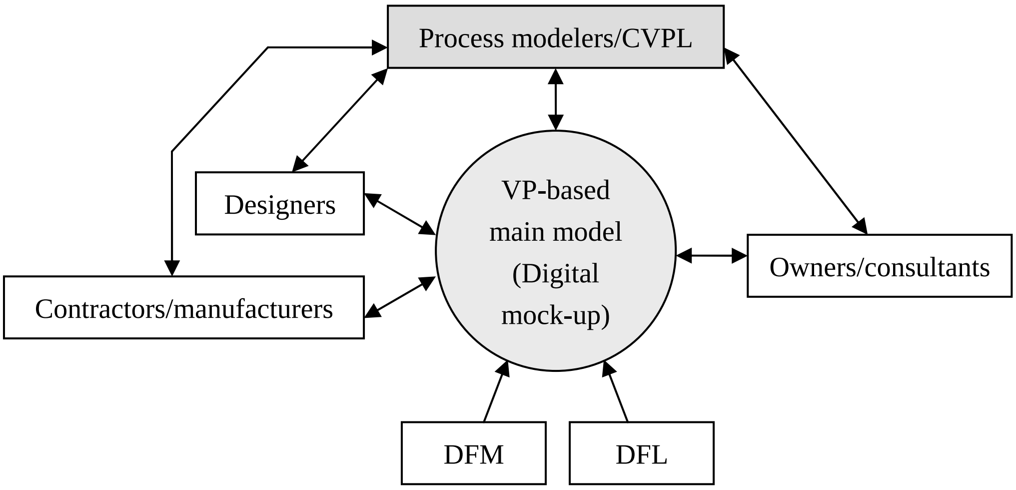


Figure 5.2 Design coordination for precast construction based on the third party

The design coordination from the IKEA model will optimize the design process of precast components and improve constructability and the transportation ability of precast buildings.

5.3.2 Production Optimization

Precast components are produced on site or off site. Each kind of production needs feasible design decomposition, that is, unreasonable design affects its production ability. This problem has been presented and solved in the previous section. Besides reasonable design, a 3D production instruction is also needed to support the production. In order to make the construction processes smooth, precast components must be produced and supplied in time in a logic sequence. However, although most production workers are skilled, it is difficult for them to follow the requirements of projects, especially for complex projects. As a result construction time is delayed. A vivid step-by-step 3D production instruction produced by VP technology is a good help to workers.

Selection of production line location of precast components is important to precast construction and it is directly related to production cost and construction time. The following several factors need to be taken into account: raw material cost, labour cost, transportation cost, and transportation time. Since construction sites are distributed in different areas, the adoption of multi-region production lines is encouraged to reduce overall cost and time.

5.3.3 Transportation Optimization

Precast components are often very large, not standardized, and difficult to transport using batch means and or using different transportation tools. This usually increases the transportation cost and time. DFL from the IKEA model makes precast components feasible and convenient to transport and makes the batch transportation of precast components possible. The time and cost of transportation is effectively reduced.

Different construction projects, furthermore, are located in different regions where the transportation situation is often not good. For example, if the entrance of the construction site is too narrow or its height is limited, some precast components might not be able to pass through it. Although the idea of DFL has been applied to design to consider the feasibility of transportation, some changes for the entrance or components perhaps take place. Thus, before precast components are transported to construction sites the transportation process should be tested in some key locations to check the feasibility of transportation. This kind of analysis is automatically conducted via the application of VP technology, i.e. the 3D models of precast components are put into the virtual environment around the construction site to check for collisions. Figure 5.3 shows the analysis of using a truck to transport precast beams to a construction site. It can be seen that the entrance of the site is so narrow that the truck cannot pass it.

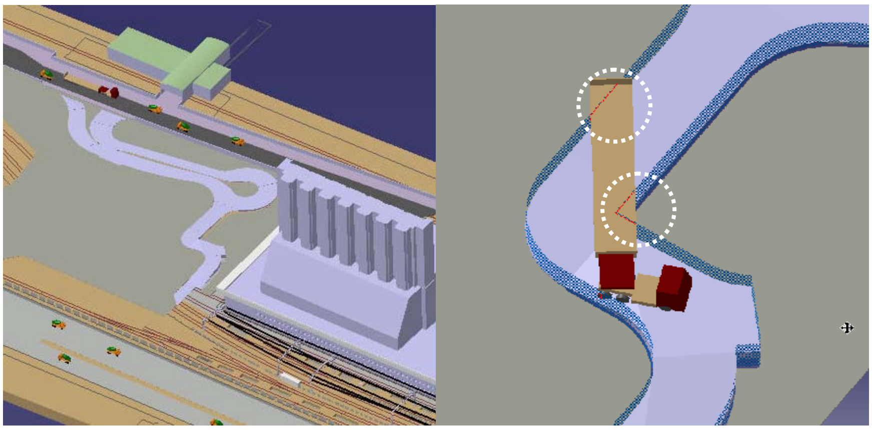


Figure 5.3 Transportation test for precast beams

5.4 Assembly Optimization

After the design, production and transportation of precast components, assembly is started. A great amount of precast components are usually installed, especially for complex projects, and some of them are very heavy and large. Many types of equipment are also used to install these precast components. In order to ensure construction time, cost and quality, a reasonable and clear installation sequence or procedure is needed. However, at present the whole progress of precast construction projects is often just guided via the application of a Gantt chart and the installation procedure is only based on the foremen's experience. This is not enough for most precast projects and usually leads to work delay, collisions among precast components or equipment, and even safety problems. Furthermore, due to the rough programme many more technicians, foremen, or safety officers are needed to manage and support the installation.

A vivid 3D assembly instruction, similar those for IKEA furniture assembly, can show the detailed installation procedure of all precast components step by step and what kind of equipments should be used. This allows everyone to better understand the installation sequence using the instruction than before. Workers could easily follow it to install precast components. This makes holistic installation processes smooth and lowers the risk of accidents happening. Also, some problems, e.g. collisions, safety, etc, can be checked in the 3D assembly instruction before the real construction commences. This may allow for some management personnel or technicians to be reduced through the combining of positions. This optimizes the management activities of construction projects and reduces management costs (see Section 4.4.1).

Besides the applications mentioned above, like cast-in-situ construction, the VP-based IKEA model also provides a construction knowledge management platform for precast construction, which will offer useful visual construction experiences for future precast buildings.

5.5 Summary

Precast construction is very different from conventional cast-in-situ construction. Although it is characterized by many benefits (e.g. rapid construction, high quality), these advantages are seldom realized in real-life construction projects. Due to its similarities to the manufacture of IKEA furniture, as presented previously, it is seen that the use of the VP-based IKEA model might improve the whole process of precast construction management.

The application of the IKEA model to precast construction, then, is analyzed via the combination of VP technology, i.e. *design-production-transportation optimization* (DFM and DFL) and *assembly optimization*. It is stated that the use of the VP-based IKEA model optimizes the design, production, transportation and assembly processes. This carries out the concept of the IKEA model in precast construction and also enables the advantages of precast construction technology to be realized.

The following chapter uses two simple real-life cases to respectively elaborate the process of applying the VP-based IKEA model to cast-in-situ construction management and precast construction management, and to test the feasibility of the model.

CHAPTER 6 CASE STUDY

6.1 Introduction

In order to test the validity of the application of the VP-based IKEA model to construction project management as proposed above, this chapter will present two real-life cases for, respectively, cast-in-situ construction and precast construction. This will elaborate the application process and discuss its effects on construction management. This chapter also aims to improve readers’ understanding of the idea of this research.

6.2 A Case Study for Cast-in-Situ Construction

6.2.1 Introduction of the Cast-in-Situ Project

Hong Kong Tseung Kwan O (TKO) Sports Ground is a design and build (D/B) project contracted to China Overseas Holdings Limited for the 5th East Asian games, to be held in Hong Kong in 2009. It is the first stadium project in Hong Kong to adopt VP technology during its construction. As the general contractor, the project team from China Overseas Holdings Limited decided to use VP technology to optimize the construction process and reduce risk and project cost. The use of the technology is based on the concept of the IKEA model.

The Hong Kong Polytechnic University, including the author, prepared the BIM (Building Information Modelling) (see Figure 6.1) for the project. The Construction Virtual Prototyping Lab (CVPL) translated the 2D drawings provided by main contractor and subcontractors into 3D models using VP technology. During the translating process, VP technology provided a communication and collaboration platform for clients, consultants, main contractor, subcontractors, and CVPL to identify, discuss, and resolve some problems such as design collisions, constructability, and so on, until an appropriate design plan was created.

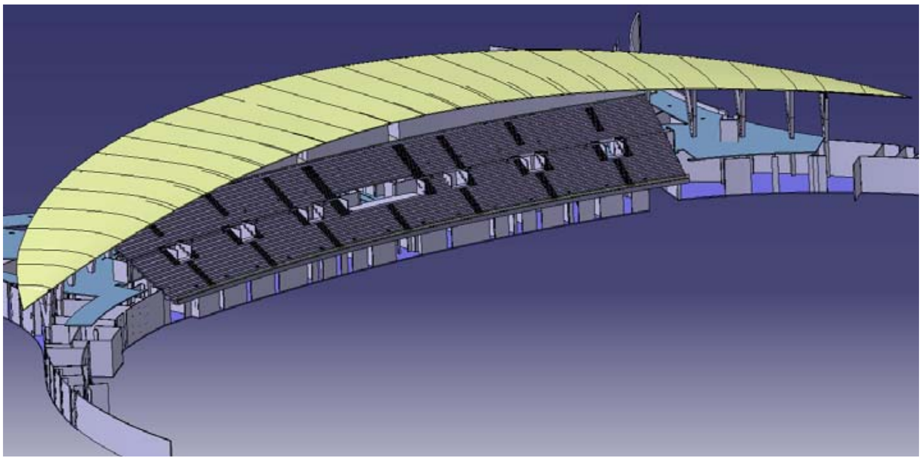


Figure 6.1 The 3D model of spectator stand

During the preparation of BIM model of the Tseung Kwan O Sports Ground project, 104 design errors were identified. By integrating the preliminary planning information, site layout, and plant and equipment, members of the CVPL conducted a simulation of the construction processes. Once the simulation model was established, project management personnel from the main contractor were invited to evaluate the feasibility of the simulated construction process and to explore ways of improving the processes. Recommendations and suggestions from the project management personnel were then used to update the simulation model. This process of evaluation was iterative until all parties were satisfied with the simulation results.

The simulation model was then offered to the site management team to guide the construction process. In order to ensure that the discrepancies between the simulation model and site reality were deal with, two members of the CVPL were seconded to the site office to work side-by-side with the project management team. Discrepancies, once detected, would be incorporated into the computer model to update the simulated construction processes so that subsequent construction activities could be guided by the simulation model.

The whole period of construction process simulation and model updating was approximately eight months. The construction project was completed in March 2008. Along with the 104 design errors detected, the simulation enabled the project to be completed 25 days ahead of schedule and the total cost was reduced by approximately 8% due to the elimination of rework and the reduced size of the on-site project management team. Details of these are presented in subsequent sections using V-column installation as an example.

6.2.2 Optimizing the V-column Installation Process

The following sections follow the sequence proposed in Chapter 4 to show the application process.

Visualization of the Construction Documents

The 3D model (see Figure 6.2) was developed based on the design drawings of the V-column structure prepared by the nominated subcontractor. This was used as a basis of further analysis, including design error checking, sequence simulation, safety and quality appraisal etc.

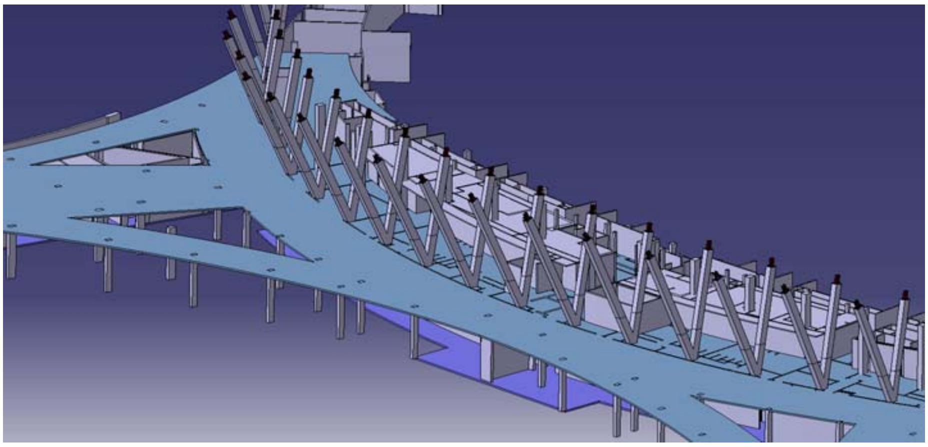


Figure 6.2 The 3D model of V-columns

Checking Design Errors

The V-column structure is a reinforced concrete superstructure composed of columns, slabs, partitions, etc. Design errors in the form of dimensional inconsistencies and collision of objects were automatically detected by the VP system. Figure 6.3 shows a clash between a V-column and structural wall. Many design errors like this were modified after they were detected. This ensured that there were zero design errors prior to the commencement of actual construction.

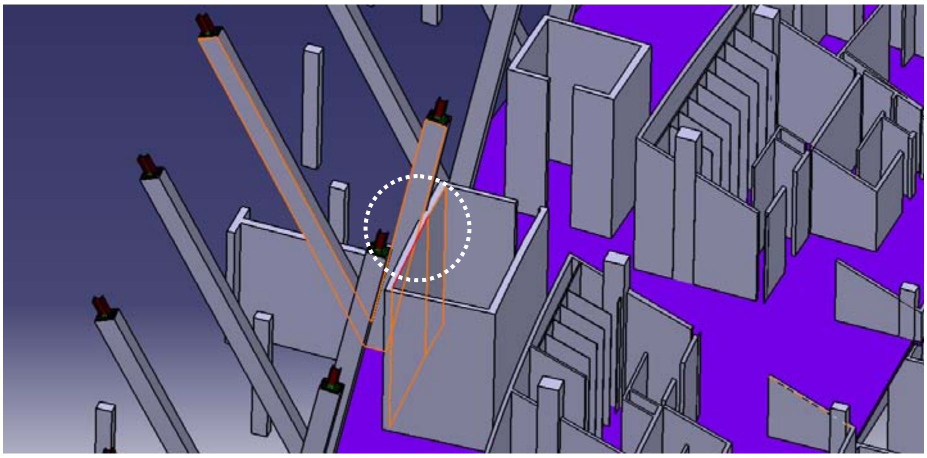


Figure 6.3 Clashes between V-column and partition

Simulation of the Installation Sequence

After the design errors were reduced to the utmost extent, the construction sequence was simulated in the virtual environment through allocating and testing appropriate materials, equipment and other resources for all construction activities. As an example, Figure 6.4 shows the construction process of a V-column, that is, a 3D construction instruction. This provides site workers or foremen with a clear construction process guide document.

Nominated Subcontractor Involvement

Before commencement of the V-column construction, the nominated subcontractor was invited to participate in the VP simulation process. The subcontractor was in charge of submitting design drawings to the main contractor for approval. Once design errors were detected, the subcontractor and the main contractor discussed the design, based on the 3D model, to confirm the modifications. Figure 6.5 shows a communication meeting on site based on the 3D environment; participants include the general contractor, the subcontractor and CVPL personnel. Moreover, the sequence simulation enabled the subcontractor to verify the coordination with other holistic on-site activities.

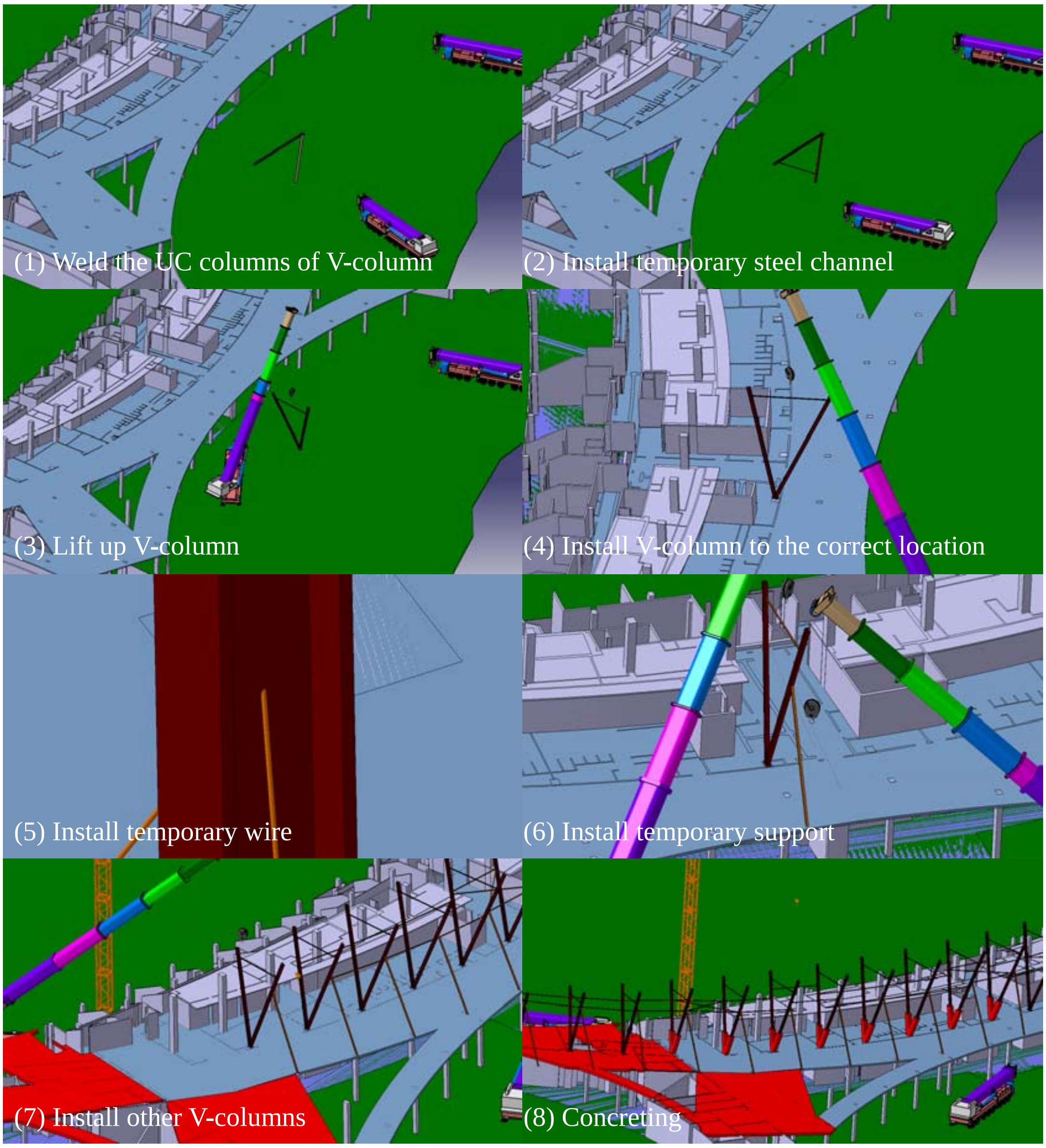


Figure 6.4 A 3D construction instruction for V-column

Quality and Safety Control

The VP technology provided an economical and risk-free visual platform to check that the design and construction process conformed to specifications. For example, in the initial installation process, no temporary support was designed to hold the V-column once it was hoisted to position. After viewing the simulation of construction sequence, the safety officer proposed that temporary wires (see step 5 in Figure 6.4) should be attached to the V-column and the roof top to ensure the stability of the column.

Figure 6.5 A communication meeting involving each party using VP technology

Training of Craft Workers

The simulation process of V-column installation was also used to train craft workers before the real construction was started to assure the applicability of the physical operation as not all workers were familiar with the techniques, materials and equipment employed in the project. Craft workers were provided with vivid and easy-to-understand instructions of the working procedure and learned operational methods through the virtual simulation environment. This reduced the amount of rework caused by operational mistakes of workers.

6.2.3 Simplification of Management Activities

In order to complete the project objectives, the contractor assigned management personnel to control different aspects of construction. The initial organizational structure of the project management team is shown in Figure 6.6. Using the VP-based IKEA model, the organizational structure was simplified and improved in two ways: 1) removing positions that become redundant after the use of VP technology, and 2) combining functions and responsibilities.

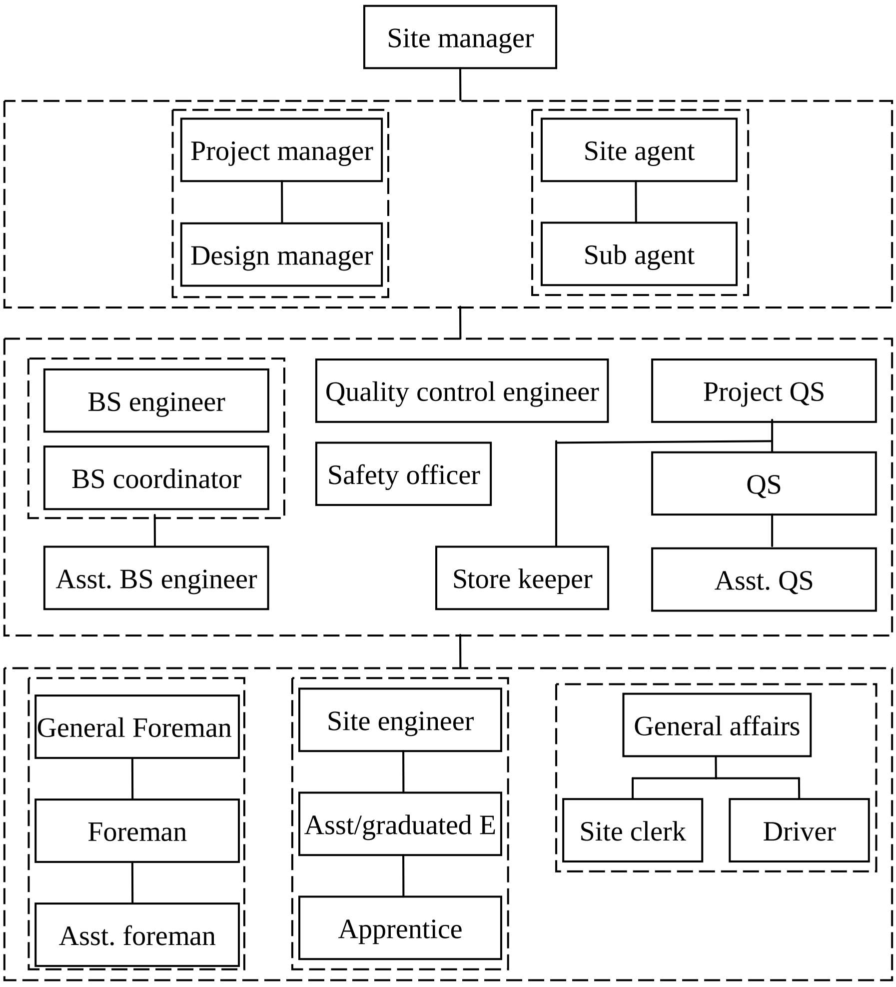


Figure 6.6 The original project organization

Removing Abundant Management Personnel

The use of VP technology made it much easier to plan and control the construction process, with project management practice being more a proactive than reactive process. In addition, as workers are given 3D instructions, less on-site supervision and monitoring personnel were required. As a result, the amount of management personnel, especially those in charge of on-site supervision, was reduced by approximately 50 percent. For example, the positions of Foreman and Assistant Foreman were removed from the project organization, and the responsibilities reassigned to the General Foreman (see Figure 6.7).

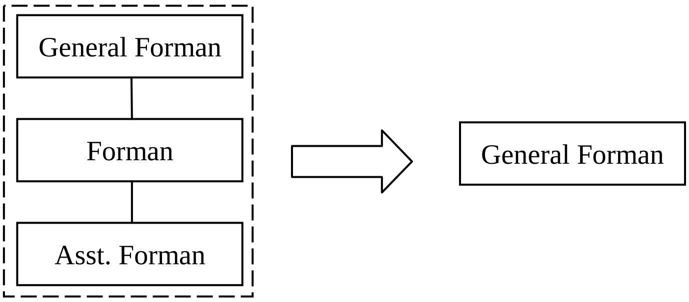


Figure 6.7 The trimmed project organization

Reduction of Management Size

In the initial organizational structure, there was a Quality Control Engineer (QCE) and Safety Officer (SO). Since the VP Technology simulated the construction process prior to the real construction, many of the potential quality and safety problems were detected and resolved in the virtual environment. As a result, the scope of QCE and SO work was reduced to the point where it is combined into just one position, as shown in Figure 6.8.

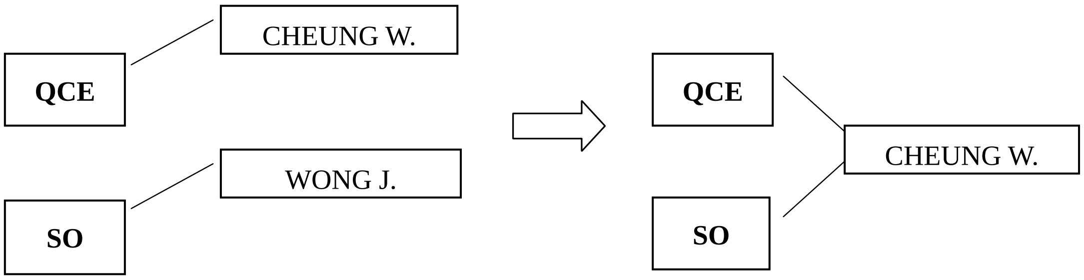


Figure 6.8 Functional combination

6.3 A Case Study for Precast Construction

6.3.1 Introduction of the Precast Project

The hotel project of this case study is a semi-precast construction project in Hong Kong and it was supported by the CVPL of The Hong Kong Polytechnic University (as the third party), which analyzed the design and installation of precast components based on the idea of the IKEA model and VP technology. Due to the on-site precast nature of the project, this study mainly takes the design, production and installation of its precast toilets as a case to explain how to apply the IKEA model to precast construction and demonstrate its feasibility and effects. Note that the toilet is assembled on the ground and then installed to a floor.

Through using the VP-based IKEA model, the design and installation of the precast toilet were efficiently optimized, design errors were detected in advance, and a 3D installation instruction was provided before the commencement of actual construction. All of these reduced construction time, cost and risks and improved its quality. The following sections describe the whole process from design to installation using the model.

6.3.2 Design Optimization

Similar to the cast-in-situ construction project, the 3D model (i.e. BIM, building information modeling) was first built and then design errors were checked for and producibility and constructability were evaluated as follows.

Transferring 2D drawings to 3D Model (digital mock-up)

2D drawings of toilets were gradually transferred to the 3D model (i.e. main model) following the design progress by CVPL personnel, including wall, slab, ceiling, glass partition, building services, temporary support, etc (see Figure 6.9). During the process of transferring, all participants communicated with each other and discussed problems through the 3D model.

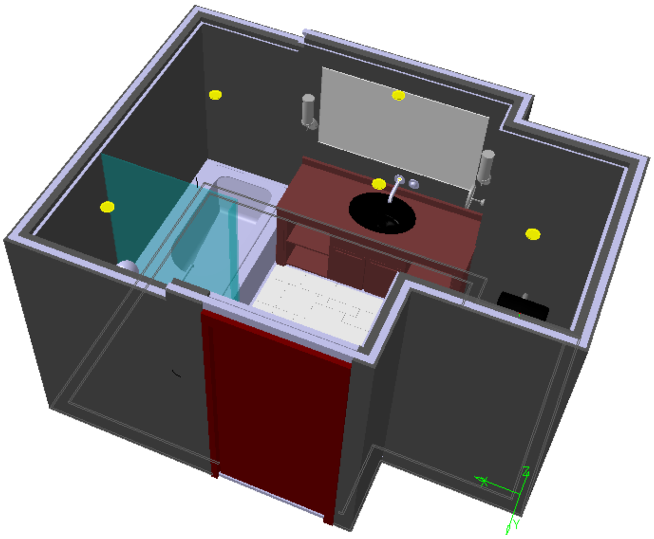


Figure 6.9 Digital mock-up of precast concrete toilet

Design Errors Checking

Based on the main model, the design was checked automatically in real time and design errors were passed to designers. After the design errors were modified the main model was also updated. Then a new design checking was conducted until no errors are found. Figure 6.10 shows a clash between the wall and the door, which is very clear and easily seen. This reduces rework for design and assembly. At the same time constructability is also evaluated to ensure that the toilet can be installed in the building, that is, the location and dimensions of the toilet is suitable for the space reserved for it.

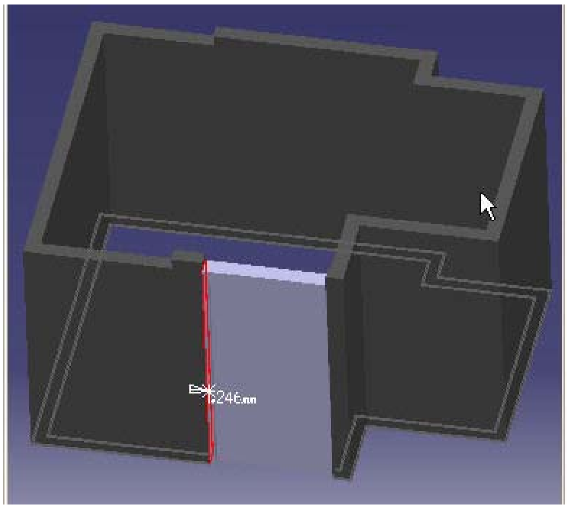


Figure 6.10 A clash between the wall and the door of the toilet

Production Feasibility Checking

For the design of precast components, manufacturers check whether these components can be produced and stored conveniently. The precast toilet is a volume precast concrete component and its production feasibility is tested in the virtual environment in advance, including its formwork system.

6.3.3 Production Optimization

Due to the on-site production of precast toilets the production optimization focused only on the production processes. In the design phase, a step-by-step 3D production instruction was produced to instruct the holistic production process of the precast toilet. This involved instructions for when and how to concrete precast toilets (e.g. erecting formwork, configuring drainage, concreting, etc) and assemble the precast concrete toilets and other prefabricated components (e.g. bathtub, cabinet, glass partition, etc). Thus the production work of the toilets was well executed in the project and time and cost was controlled effectively.

6.3.4 Installation Optimization

The installation of precast concrete toilets was a big challenge for the project as the precast toilet was a complete concrete toilet which involved bathtub, partition, cabinet, drainage, etc and was very heavy and large. Collisions or accidents could have easily occurred. Especially after hoisting a toilet to the right floor of the hotel, it was difficult to move it to the design location. Another challenge was to connect the drainage of one toilet to the one of another toilet. After adjusting a toilet to its design location, its drainage needed to be connected with the drainage of toilets above and below. The slab under the toilet needed to be excavated in advance in order to offer work space for the connection between drainage. The location and size of holes needed to be appropriate.

Before the real installation of precast toilets commenced, the installation sequence was tried in a virtual environment many times until an appropriate installation procedure was found. At the same time, a detailed 3D installation instruction was built as shown in Figure 6.11. Thus safety was ensured and rework cost and installation time were reduced. Besides this, since some safety problems and technical problems were solved in advance, safety officers and technicians were reduced to a great extent. This also reduced the management cost of the project.

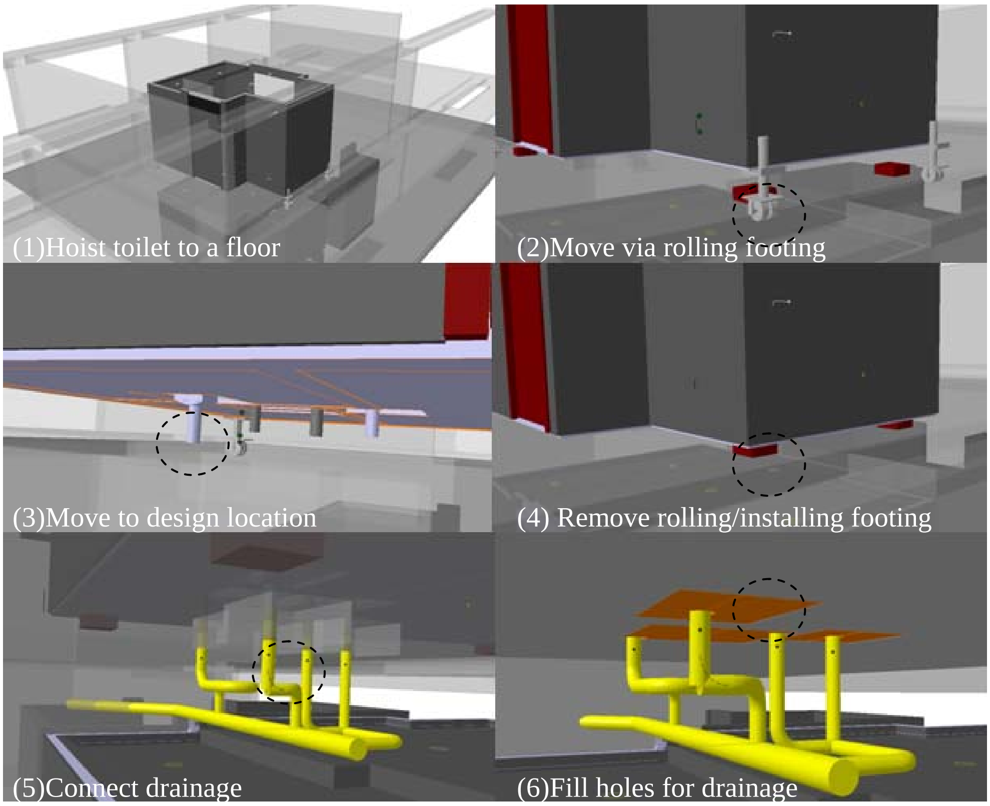


Figure 6.11 A 3D installation instruction for a precast toilet

Besides this, like cast-in-situ construction, the 3D construction instruction was also adopted to train on-site workers and the holistic management activities were also refined in the project.

6.4 Discussion

From the above two cases, it is shown that the VP-based IKEA model can improve construction project management by reducing construction time and cost, improving construction safety and quality, etc. Besides these two projects, the VP-based IKEA model has been applied to other real-life construction projects in Hong Kong and Macau, in order to demonstrate its feasibility and validity, the cost and time saving is summarized (see Table 6.1). Kwai Chung Public Housing and Ho Tung Lau are two precast projects; other two projects are cast-in-situ. Due to the confidential data of the precast project mentioned above, its data is not shown here.

Table 6.1 Cost and time savings in construction projects

Project name	Cost saving	Time saving
Kwai Chung Public Housing	Unclear	About 17%
Ho Tung Lau	About 12%	About 5%
Venetian Macau Hotel	About 5%	Unclear
TKO Sports Ground	About 8%	About 25 days

Note: that all data are collected from relevant contractors and in some cases the situation is unclear due to lack of data.

It is shown from Table 6.1 that construction time and cost can be reduced respectively by 5% or above and 8% or above through the application of the VP-based IKEA model. Especially for precast projects, the time and cost saving is remarkable, and to some extent, this means the VP-based IKEA model benefits precast projects more than cast-in-situ projects. Note that, relatively, time and costs needed for conducting VP technology are very few or low. It is believed that the productivity of the construction industry can be improved by extensively adopting the VP-based IKEA model.

6.5 Summary

Two cases, i.e. TKO Sports Stadium project and Hotel project, are analysed to test the effects of applying the VP-based IKEA model to, respectively, cast-in-situ construction management and precast construction management. For the former, the constructability of the design of the V-columns was evaluated to reduce reworks, a 3D construction instruction for the V-columns was presented to guide construction, and management activities were simplified to cut down management cost. For the latter, the producibility and constructability of the design of precast toilets was estimated and then a 3D installation instruction for the toilet was built.

From the two cases studies, it is demonstrated that the application of the IKEA model to construction project management (whether cast-in-situ or precast) based on VP technology is not only feasible but also valid. It has an important role to play in the improvement of construction project management.

CHAPTER 7 CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

This chapter presents the conclusions of the research including research findings, the contributions and limitations of the research and offers some suggestions for future research.

7.1 Research Findings

The construction industry has low productivity and the main reason identified for this is traditional construction project management methods. As discussed in Section 1.1, the productivity of the manufacturing industry has been increasing while that of the construction industry has remained slow in the past several decades. This is because conventional construction project management methods make reworks during design and construction processes happen often and make management activities complex and reactive. This wastes construction time and cost and may also reduce quality. On the other hand, innovative management methods are immature.

This research proposes a new alternative for construction project management in order to solve current problems. The IKEA model, based on customer-assembly of products, has been successfully used in the car manufacturing industry to improve productivity and reduce costs and prices and has some potential for application in the construction industry. Likewise, VP offers a means of testing out production processes in advance of actual construction – a vital aspect for construction projects, which are often of a bespoke nature. This research presents an application to the construction industry (including cast-in-situ and precast) using the VP-IKEA combination with 3D instructions. A case study is described based on two real-life projects in which both efficiency and productivity were considerably improved. The details of research findings are described as follows.

1) ***The IKEA model proposed in this research is feasible for the construction industry in theory, experience and practice.*** The IKEA Group has made a rapid development in its market and it is believed that its approach can offer a reference for construction management. This is first demonstrated using a questionnaire survey and a comparison analysis between IKEA furniture and the construction industry and then tested via its application in real-life cases. These show that the integration of the IKEA model with VP technology can improve the construction project management level. Therefore, it is believed that learning from the manufacturing is an effective and efficient method to improve the productivity of the construction industry.

2) ***The process of application of the IKEA model to cast-in-situ construction management is established using VP technology.*** Two aspects of applications are presented, that is the optimization of construction processes and the simplification

of management activities. The former consists of design error checking and constructability evaluation, 3D construction schedule establishment, the identification of unsafe zones and quality problems, the provision of effective communication platform for all participants, and construction knowledge management; the latter focuses on the simplification of the document submission process and the rearrangement of the roles and responsibilities for project managers. The application greatly benefits current construction management.

3) ***The process of applying the IKEA model to precast construction management is built using VP technology.*** Due to the differences between cast-in-situ and precast construction, besides some applications similar to cast-in-situ construction, the application of the IKEA model to precast construction mainly focuses on design coordination between all parties, production optimization, transportation optimization and assembly optimization, and especially regarding design producibility, transportability, and assemblability. It is found that the application of the IKEA model in precast construction is more feasible than that in cast-in-situ construction.

4) ***Advanced information technology is a key to success in innovative management in the construction industry.*** From the holistic study, it can be seen that VP technology offers an important and necessary support to the use of the IKEA model in construction project management. If there was no support from VP

technology, this study could not be conducted. This is determined by the unique features of the industry, e.g. fragmental, unrepeatable construction processes, unique, etc. Meanwhile, time and costs needed for adopting VP technology are relatively few or low. Therefore, this research may indicate that advanced IT is a key factor of successful management innovation in the construction industry.

7.2 Contributions of the Research

This research puts forward the VP-based IKEA model and applies it to the construction industry. This not only improves the productivity of the construction industry but is also a new effort to introduce the successful experiences of the manufacturing industry to the construction industry.

1) ***An effective construction project management method is provided for project managers.*** Combining the IKEA model with VP technology enables the use of the IKEA model in the construction industry. Whether for cast-in-situ construction or for precast construction, the optimization of design and construction processes reduces design errors and construction uncertainties and therefore great deals of reworks are reduced before the commencement of actual construction. Management activities are simplified, reducing management costs. For precast construction, the use of the VP-based IKEA model in design for production and transportation offers project managers an effective and efficient support. This

lowers costs, reduces time, and improves quality and safety and productivity is enhanced. All of these have been demonstrated in the case study.

2) ***This research may impel the development and innovation of the whole construction industry.*** One of the implications of using the VP-based IKEA model is that, in addition to significant time and cost/price reductions, a radically simplified management structure that is more closely aligned to that of manufacturing is possible. If adopted on a large scale it is likely that the construction industry itself will become organised much more along the lines of manufacturing, with a greater use of prefabricated components, standardised assembly processes and concomitant reduction in risk and uncertainty over time, price and quality levels achievable in the industry. At that time the industry can be holistically changed.

3) ***A new direction is proposed for applying manufacturing management methods to the construction industry.*** Learning from the manufacturing industry is a useful approach to improving the productivity of the construction industry and to solve problems arising from construction processes. A lot of efforts have been made to introduce manufacturing management methods to the construction industry. However few successes have been achieved. This research provides a new direction for learning from the manufacturing industry, especially the use of VP technology, and enriches construction project management theory.

4) ***This research offers a successful case for using VP technology in the construction industry.*** VP technology arises from the manufacturing industry and has begun being used in the construction industry. It shows a potential to improve construction management, but it is still in its infancy. This research fully employs the functions of VP technology through its integration with the concepts of the IKEA model. Thus this provides a strong case for deeply using VP technology in the construction industry.

7.3 Limitations of the Research

Although some findings and contributions are achieved in this research, it is necessary to note that the focus of the research is just to explore the use of the VP-based IKEA model to reduce the rework and management cost of a construction project. Some other successful experiences of the IKEA Group are not covered in this research, for example, the successful logistics system of the IKEA Group, the selection criteria of production sites of prefabricated components, and the cost-control mechanisms of the IKEA model. VP technology adopted in the research is not still widely used in the construction industry and this limits the extension of this research. Besides these, some of the applications of the VP-based IKEA model to CPMa cannot be smoothly implemented, for example the identification of safety and quality problems, and the simplification of the document submission process. All of these might be investigated in future research.

7.4 Suggestions for Future Research

To address the limitations mentioned above, further research is needed and some suggestions for this are presented as follows.

1) ***To explore the possibility of adopting the cost-control mechanisms of the IKEA model into a construction project delivery process.*** The application of the IKEA model in design and construction processes reduces reworks and therefore time and cost are saved. The improvement of productivity benefits not only contractors or subcontractors but also owners. However, at present it mainly benefits contractors. The cost-control mechanisms of the IKEA model can provide a guide for the reasonable allocation of these benefits, and the method for this is to control the construction project delivery process.

2) ***To study the selection of production sites of precast components.*** The production site of precast components relates to the production cost and transportation cost. In different regions the cost of raw materials and labour is different which determines production cost and transportation cost. IKEA adopts a multi-region manufacturing policy for the production of its furniture, effectively reducing cost and transportation time. Future research may take into consideration the site selection of manufacturing precast components based on the concept of the IKEA model.

3) ***To introduce the logistics system of the IKEA Group into the construction industry.*** The study of construction logistics has become prominent in recent years, but it is still not conducted successfully. As we know, IKEA's successful logistics system has made a great contribution to its development. Due to the similarities between IKEA furniture and the construction industry it is believed that the logistics system can provide a reference for the construction industry, especially for precast construction.

4) ***To further test the effects of the VP-based IKEA model in more construction projects.*** Although a lot of similarities exist between IKEA furniture and the construction industry, they are different industries and the construction industry has a bespoke nature. The application of the model in the construction industry must be continuously tried and adjusted until it is totally suitable to the industry, especially for the identification of safety and quality problems and the simplification of document submission processes.

5) ***To deeply study the application of VP technology in the construction industry.*** VP technology originates from the manufacturing industry. Many difficulties and barriers to the adoption of VP technology in the construction industry have been elaborated in Huang et al. (2007). These need to be further investigated in future research.

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APPENDIX I A QUESTIONNAIRE FOR INVESTIGATING THE MMM'S APPLICABILITY FOR THE CONSTRUUCTION INDUSTRY

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

DEPARTMENT OF
BUILDING & REAL ESTATE
建築及房地產學系

16 March 2007

To: Managers/experts in the field of construction project management

Dear Sir/Madam,

Re: A Survey for Using the Manufacturing Management Approach to the Construction Industry

I am writing to invite you to participate in our survey which is intended to **examine the feasibility of the manufacturing management method of the manufacturing industry to the construction industry empirically**.

As we know, the construction industry has a low productivity in past several decades due to some problems (e.g. time delay). It is expected to solve these problems through the application of the manufacturing management method in the construction industry. Owing to the differences between the two industries, it is necessary to investigate the feasibility of the manufacturing management method for the construction industry. Note that the IKEA Group, as a typical representative of the manufacturing industry, has a lot of similarities to the construction industry (e.g. the assembly of IKEA furniture and the installation of precast components) and therefore this research mainly focuses on the use of the IKEA approach in the construction industry.

In this questionnaire, you are asked to provide your ideas about this on the basis of your experiences. Specifically the problems in current construction management and the reasons for them, your expectation for construction management innovation, and the feasibility of the IKEA approach for the industry are asked. I hope this work could benefit your company and the outcomes will be sent to you when available.

I would be mostly grateful if you or your colleagues complete the attached questionnaire and return it to me through Mail, Email or Fax on or before 10 May 2007. (**Please feel free to copy the enclosed questionnaire for completion by your colleagues.**) It is assured that your response will be treated with absolute confidentiality and just used for the research. If you have any questions, please feel free to contact me.

Thank you very much for your contribution and look forward to receiving your reply.

Yours sincerely,

Mr Hongling GUO

PhD student
Department of Building & Real Estate
The Hong Kong Polytechnic University
Tel: (852) 2766 5803
Fax: (852) 3400 3382
Email: samuel.guo@

Encl.
A copy of questionnaire
An addressed and freepost envelope

Cc: Prof. Heng LI

INSTRUCTION:

Please answer all these questions listed below according to your own experiences in construction management. It will take you about 10 minutes to complete the questionnaire. Please be aware that your responses will be kept in strict confidence.

1. Basic information

1. Type of organisation you are working in:
☐Client ☐Architecture ☐Engineering
☐Building services ☐Project management consultant ☐Contractor
☐Subcontractor ☐Research institute or university ☐Others (please specify)_____

2. Your position: __________

3. How long you work in the field of construction management: __________

2. Project management information

4. The possibility of some problems happening to construction project management:
☐Very low ☐Low ☐Medium ☐High ☐Very high

5. What kinds of problems often happen to construction processes?
☐Time delay ☐Cost overrun ☐Quality problem
☐Safety problem ☐Environmental problem ☐Others (please specify)_____

6. The reasons for time delay:
☐Design problem ☐Bad construction management ☐Unpractised workers
☐Changes from the client ☐Low-level construction technology
☐Bad weather or irresistible reasons ☐Others (please specify)_____

7. The reasons for cost overrun:
☐Design rework ☐Construction rework ☐High management cost
☐Changes from the client ☐Increasing resource cost ☐Others (please specify)_____

8. The reasons for quality problem:
☐Design problem ☐Construction problem ☐Management problem
☐Supply of raw material ☐Others (please specify)_____

9. The reasons for safety problem:
☐High complexity of design ☐Low-level construction technology
☐Unpractised workers ☐Inappropriate construction processes
☐Low safe awareness or training level ☐Others (please specify)_____

10. The reasons for environmental problem:
☐Unreasonable design ☐Low construction technology
☐Inappropriate construction processes ☐Others (please specify)_____

3. Project management innovation

11. The degree of your expectation to solve these above problems via management innovation:
a ☐Very low b ☐Low c ☐Medium d ☐High e ☐Very high

12. If choose a or b in Q11, please specify the reasons (or skip this question and direct to Q13):
☐The innovation is impossible ☐Possible but very difficult ☐Others (please specify)_____

13. What is your expectation for the innovation?
☐Design concept ☐Design means or tool ☐Construction technology
☐Construction process management ☐Communication means ☐Worker's training
☐Refining the management team ☐Logistics management ☐Others (please specify)_____

14. Aiming at your own expectation, do you have some suggestions for it? If any, please specify: ____________________

4. The IKEA production management method and project management

15. How about your knowing about IKEA furniture?
☐Not yet ☐A little ☐Roughly ☐A lot

16. The similar degree between the IKEA design and production process and the design and construction process of buildings:
☐Very low ☐Low ☐Medium ☐High ☐very high

17. Could the design coordination concept (design for manufacturing and logistics) of IKEA provide a reference for the design of construction projects?
☐Very low ☐Low ☐Medium ☐High ☐very high

18. Could the idea of 3D assembly instruction-based self-service provide a reference for the construction of construction projects?
☐Very low ☐Low ☐Medium ☐High ☐very high

19. Could the logistics system of IKEA furniture provide a reference for the logistics of the construction industry?
☐Very low ☐Low ☐Medium ☐High ☐very high

20. Could the 3D technology used in the design and production process of IKEA furniture provide a reference for the construction industry?
    ☐Very low ☐Low ☐Medium ☐High ☐very high

♦ The End. Thank you very much again for your support! ♦

It would be appreciated very much if you could write down your suggestions for this research and questionnaire.

If you would like a summary report of the questionnaire survey, please write down your correspondence information below. I promise the information will be solely used to send the report to you.

Name：
Email：
Address：