

# MINIMISATION OF RISK EXPOSURE AT THE PRE-PRODUCTION STAGE THROUGH THE USE OF CONTRACTOR-LED DESIGN MANAGEMENT

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Many large scale construction projects (LSPs) are designed in a collaboration between famous international architects and local design firms. Design management usually evolves as a tool at the design stage for designers and design solution. One of the special characteristics of the Korean construction environment places a duty and responsibility on the contractor to coordinate and check design information. Hence the contractor must manage and integrate diverse design information into the production process. This research considers how the design management diagram (DMD) can help as a part of the system at the pre-production stage of LSPs in Korea<sup>2</sup>. The pre-production stage receives insufficient attention from the research community from the perspective of design management; it is a complex process involving interdependence, risk, and uncertainty. Through the application of a DMD from the pre-production stage, the contractor can predict and manage the design-related uncertainty during production stages. The design management factors (DMFs) were analysed by the analytic hierarchy process (AHP), and then used complexity system theory to understand the interrelationship between the causal factors. DMFs are presented as a causal loop diagram which can help the contractor to cope with design-related uncertainties at the early production phase.

Keywords: causal loop diagram, contractor-led design management, international design team, pre-production stage.

## INTRODUCTION

Construction projects are being increased in size, scale, and complexity. The contractor must calculate the production cost and the time requirements, and then establish the appropriate execution strategy at an early stage. Large scale construction projects (LSPs) incorporate lots of design elements that require unique and innovative structural, mechanical, lighting, electrical, and environmental systems (Aminmansour and Moon, 2010). The complex technologies and systems with different requirements for expertise including specialist, subcontractors and suppliers more increase the project complexity. In addition, international design team involved in the design process add another layer of complexity that the contractor must manage. Such design teams are influenced by different culture, technical standards, and work processes, making design collaboration challenging. Such arrangements often results in a complex for the delivery of the design information to the contractor. This has led to project cost overruns, time overruns, and poor profitability for Korean contractors.

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<sup>2</sup> For the purpose of brevity, Korea has been used throughout the document to denote the Republic of Korea, which is South Korea.

It is very difficult for the contractor to address these complexities and uncertainties during production stage. They have to establish the appropriate production strategy and prepare a suitable implementation plan within the short period of the pre-production stage (Song *et al.*, 2009). During the pre-production stage, the time constraint means lots of critical elements are overlooked. Thus, the contractor should retain the appropriate method to manage the design information. The contractors need to convert the design information into production information. Moreover, contractors should consider the assembly of the construction team, the pre-ordering of materials, and the planning of production prior to work commencing at pre-production stage. However, contractor normally does not have their own design management team to manage the diverse and complex design information. Particularly, under multinational complex projects, contractors have suffered from the uncertainty caused by insufficient management of design information. This can directly influence rework, duration, and profit at production stage (Lopez and Peter, 2012).

Insufficient attention has been given to the effective management and use of design information at the pre-production stage. This research focuses on how design management at pre-production stage can help the contractor to recognize design-related uncertainties and prepare appropriate execution methods. The aim of this research is the establishment of a DMD from the contractor's perspective to manage the design-related uncertainty at the pre-production stage. It will be useful particularly for Korean construction enterprises working on LSPs designed by international design teams. Based on complex system and system thinking as an underlying theory, factor interdependent causal loop diagram was established as a DMD in order to understand how DMFs influence the practical production stage.

## **PROJECT DELIVERY IN KOREA**

Large contractors who are part of a large conglomerate dominate the Korean LSP market. These large conglomerates have both moral and legal responsibility to deliver projects; they are an important part of the business and social infrastructure of Korea. The general contractor as an affiliate of a conglomerate takes a total responsibility for project delivery. Legal and statutory responsibility lies with the contractor to ensure engineering integrity of design. Legally a contractor has to review and confirm the integrity of drawings and documents along with the project supervisor before commencement of construction (Bea *et al.*, 2006; Moleg, 2014). When contractors take over a project from the architect they have to check all the design and documents, and then establish the implementation plan to manage the design-production elements. International design teams, in many cases in Korean LSPs, rely on contractors to respond quickly to unexpected problems on site, even though the initial problem may have been caused by insufficient or incorrect design information.

Almost all large contractors in Korea act as a construction manager and as a design manager on the project as well. Because there is no practical concept of a project manager in the Korean construction industry, the design management team undertakes large parts of the project manager's role. Design management team is closely interconnected with all production stages as well as influencing project productivity and performance; it is one of the main reasons that the research focused upon contractor-led design management.

Many large Korean conglomerates have diverse subsidiary companies in the construction industry such as developer, contractor, consultant, and provider of heavy equipment and construction materials as part of their business. When the large

conglomerates develop a LSP, consideration is given to different business aspects directly related with their subsidiary companies. Subsidiary companies constantly request design or material changes in order to supply a certain material or equipment which they produce or trade (Kim and Kown, 2005). At the early project stage, the contractor who controls the LSP should analyse and manage all of the design-production elements requested from brother companies to reduce unexpected risks.

## **LITERATURE REVIEW**

### **Project complexity**

The emergence of complexity brings new questions to the construction project in the age of chaos and interdependence. Studies associated with complexity, chaos and uncertainty are steadily increasing in project management research literature (Austin *et al.*, 2002).

Thomas and Mengel (2008) defined complexity from the systematic perspective. They insisted that complex systems are made up of large numbers of multiple-interacting components in which it is difficult to understand the behaviour of the individual components or predict the overall behaviour of the system. In accordance with the study by Vidal and Marle (2008), a synthetic approach can be taken into account for management of complex projects in which different participants will have different perspectives. They assert that synthetic integration of individual characteristics is useful in understanding how the complex personalities can be perceived as a part of project. Migliaccio *et al.* (2008) also investigated implementation of complex projects. They consider design aspects to address rapidly changing construction elements. From the investigation, barriers and facilitations to understand the comprehensive interconnection between individual design and construction elements were presented. They developed a framework to cope with design-related construction elements caused by multinational participants and off-site materials.

Complexity is a feature of a project which makes it difficult to understand, foresee and keep under control its overall behaviour, even when given the complete design information (Owens *et al.*, 2011). Thus, appropriate management of design information is essential for reducing uncertainty risk at early project phase.

### **Contractor's design management**

In design management literature, the research of contractor-led design management started with the shift of procurement from the 1990s. Gray *et al.* (1994) describe the growing importance of contractor's design management (Gray and Hughes, 2001). Contractor's design management was the coordination and regulation of the building design process, resulting in the delivery of a high-quality building. Design management texts have not emphasized sufficiently how contractors can manage the design information and process for the production stage and the challenges they face.

However, different research is being carried out on contractor's design management more recently. Emmitt (2007) found that due to the complexity of current building projects, management responsibility of the contractor has risen even in design aspects. He argued that the contractor should be involved more substantially in the management of design information. Broadbent and Laughlin (2003) emphasised the importance of systematic design management. From the contractors' point of view, design management is a function that coordinates the design information to deliver high-quality performance, enabling the needs of the design, manufacturing, and construction processes to be met. There are more substantial studies dealing with the

contractor's role in design process. Walker and Walker (2012) also studied contractor's early involvement on project; they suggested that because contractors have practical experience of design-related problems on site, they should be involved from the initial project phase as soon as possible.

The role of design management is becoming more systematic and contractor-oriented. Like above studies, involvement of contractor-led design management from initial stages is expanded by improved schedule, cost, safety, and quality performance (Emmitt, 2010).

## RESEARCH METHOD

This research focuses on the understanding of the current problems and practical ideas from the collected and analysed data. This research is structured into three parts: the factor identification, data collection, and data analysis. 40 potential DMFs were obtained from diverse academic literature and industrial data. After semi-structured interviews by 11 experts in the construction industry, 21 DMFs were determined to constitute the survey questionnaire. Interviewees were asked to evaluate the appropriateness of selected factors and to add any additional DMFs. The questionnaire was divided into two parts. Part 1 acquired personal and general information. Part 2 evaluated the degree of importance of each factor and the interrelationships between factors. Questionnaires were issued to Korean construction professionals engaged in international-based LSPs as a project manager, site manager, project engineer, or design manager. All respondents were selected from Grade 1 contracting and engineering firms registered with the International Contractors Association of Korea, or the Korea Construction Engineers Association.

284 questionnaires were distributed and 98 valid responses were returned representing a response rate of 34% which is an acceptable response rate for a questionnaire survey. Among the 98 sample, 24 respondents (24.5%) were construction managers, 32 (32.6%) were site managers, 31 (31.6%) were project engineers and 11 (11.3%) were design managers. The majority of the respondents (78%) had over 5 years working experience in their organizations. They were all at middle or higher management levels, which indicate that a high level of accuracy and credibility of the collected data were achieved.

Statistical methods were used for the analysis. The analytic hierarchy process (AHP) was used for data analysis. AHP analysis uses a hierarchy to resolve a decision problem, and then develops priorities for the alternatives throughout the system (Saaty, 1987). Each survey question was designed for pair-wise comparison, thus interrelationships between two target factors can be evaluated and analysed more substantially. Through the pairwise comparison, a more accurate relationship between two target factors can be achieved than result from statistical group response (Whang and Kim, 2014). The respondents selected one DMF which was deemed more critical between the two target factors by people with actual project experiences or professional knowledge. By the above procedure, the importance of each DMF was evaluated, and also the degree of the relationship between two compared factors was presented. Based on the results, all factor interrelationships were shown alongside how strong the relationships are between the factors and which factors have multi-relationships with other critical DMFs.

The importance and priority weight of each factor are ranked and shown in Table 1 with Figure 1 showing the different interrelationships among factors. Based on factor

interrelationships in Figure 1, synthetic causal loop diagram was established as seen Figure 2.

## DATA ANALYSIS AND DISCUSSION

### Importance weight evaluation

Important weights of all DMFs are evaluated by AHP analysis. The first step of AHP analysis is to classify a hierarchy by organizing the critical DMFs. The next stage evaluates the relative importance of each factor using a set of pair-wise comparison matrices by a nine-point scale using a scale from 0\_(lowest level) to 9\_(highest level) (Al-Harbi, 2001). The survey respondents selected one factor that seemed to be more important corresponding to the factors being compared. According to the respondent's determination on a chosen factor, importance weight of each DMF was estimated. AHP also measures the overall consistency of judgments by means of a consistency ratio (CR). The CR provides a way of measuring how many errors are created when providing the professional judgment (Saaty, 1987). If the CR is below '0.1', the errors are fairly small and thus, the final estimate can be accepted. If it is more than '0.1', the judgments may be somewhat random and should perhaps be revised. After CR checking, if the figures present inconsistent results, judgment should be repeated.

The priority of the DMFs was also presented as a concrete figure according to each weighted result as seen in Table 1. Unlike importance weight, factor priority allowing multiple responses means favourable and acceptable factor by construction experts. In other words, even if high priority factors cannot be perceived as very important, they are recognized as indispensable in design management. Thus, these DMFs would be considered and applied into the real LSPs.

Through the AHP analysis, all DMFs have both importance and priority weight. Among 21 factors, management of the design interface between international design firms (F17), standardization of different types of drawings (F7), proposal of value engineering (F3), and integrated design management teams on-site (F5) are ranked as the top four critical factors. In comparison to other factors, they have significantly high importance weights (at least over 9%). The sum of these four factor weights is more than 40% of the total weight. Because these four factors can influence the whole project duration and performance, they can be incorporated into the project design management process at the initial project stage.

Oppositely, low ranked factors have specific and regional features. For example, some factors focus on multinational aspects such as building code interface management between different global standards (F16) and regular detailed design meetings with subcontractors and suppliers (F12). The other factors including changed data management during production stage (F20) and prior discussion on major buyer's requirements (F18) are directly related with Korean features. The sum of the importance weight of the 5 lowest factors (11.372) is less than weight of the highest factor. However, because these factors are interconnected with diverse factors as seen in Figure 1, from the systematic perspective, they can influence high ranked critical factors.

Table 1: Importance weight and priority result

No	Design management process factor	Rank	Importance Weight (%)	Priority Result (%)
F17	Management of design interface between international design firms	1	11.678	6.128
F07	Standardization of different types of drawings	2	10.231	6.016
F03	Proposal of value engineering	3	9.267	4.425
F05	Integrated design management team on-site	4	9.086	8.112
F01	Project documents review	5	6.138	9.015
F06	Application of BIM	6	5.232	7.261
F02	Review of the design level compared to budget	7	4.592	3.623
F15	Changing design coordination	8	4.461	5.063
F04	Application of project management information system	9	4.188	3.727
F09	Documents management according to Fast-Track	10	3.872	5.152
F10	Structural grid planning review(over design, omission)	11	3.731	3.521
F14	Off-site construction manual and guideline	12	3.627	3.368
F19	Interior finishing simulation	13	3.468	3.362
F08	Establishment of design integrity checklist	14	3.374	3.492
F21	Support for an environmental building certification	15	3.142	3.427
F11	Making criteria for pre-assembly process on site	16	2.541	3.127
F13	Approval working drawing and sample material	17	2.497	6.113
F16	Building code interface management between different global standards	18	2.484	4.540
F20	Changed data management during production stage	19	2.303	3.051
F18	Prior discussion on major buyer's requirements	20	2.059	3.214
F12	Regular detailed design meetings with subcontractors and suppliers	21	2.029	4.263

\* Priority results include multiple responses

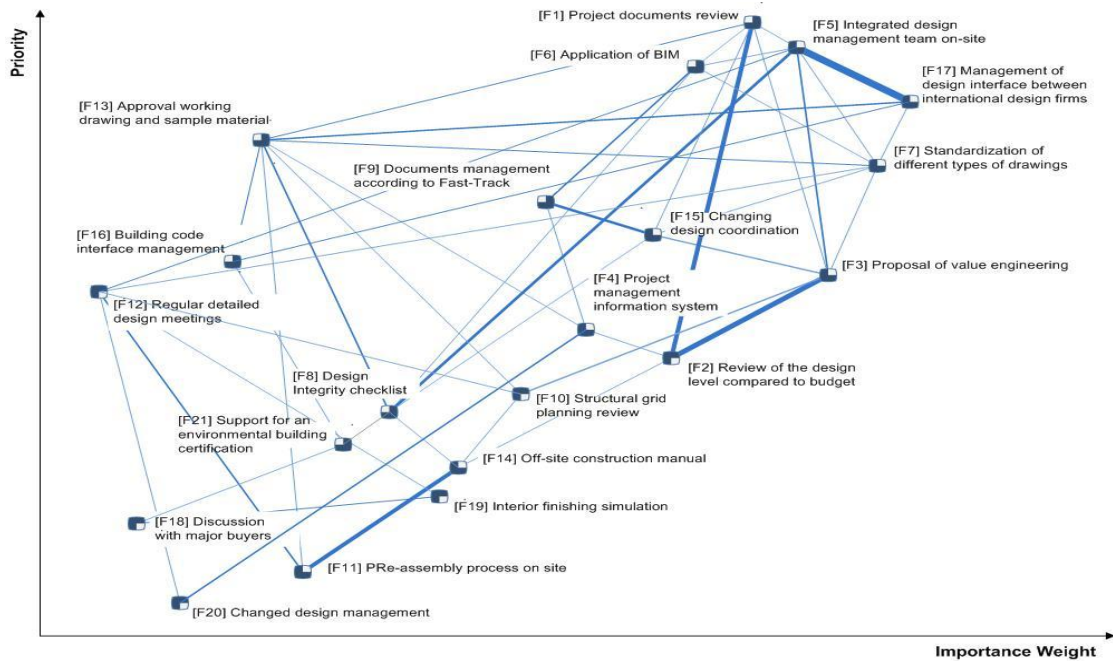
### Factor interrelationship evaluation

Factor interrelationships are meaningful as much as the importance weight. All DMFs can have advantageous or disadvantageous impacts on project performance simultaneously. In addition, some factors which are quite advantageous in the early stages can have serious influence on the project performance later on. For example, Application of BIM (F6) factor can be advantageous to improve productivity. However, at the same time it also can cause the increase of construction cost and duration due to out-sourcing costs for BIM modelling and training cost for BIM operators.

In Figure 1, all DMFs are located on the graph based on priority and importance weight. Herein, factors which have strong and closed relationship with other factors are expressed as bold and thick lines according to the questionnaire response. Overall, high priority factors have diverse relationships with other factors, while high importance weight factors have more strong relationships comparatively. Figure 1 indicates that high ranked factors in both importance weight and priority such as F1

and F5 have various and strong relationships with other factors at the same time. Indeed, these kinds of factors can have a dominant influence on whole project performance, particularly in small and middle size projects. However, in international-based LSPs, the efficient integration of diverse factors is more critical than focussing on a small number of predominant factors. Thus, even if some factors do not have high importance weight such as F12 and F13, they can play as a hub factor having diverse interrelationships with other DMFs; indeed F12 and F13 have 8 and 6 relationships with other factors respectively.

Figure 1: Interrelationship between design management factors



## CAUSAL LOOP DIAGRAMS

The traditional management approach assumes that if each project component can be understood, then the whole project can be controlled easily. However, the interrelationship between components of LSPs is more complex than the linear thinking system from the traditional approach. Thus, comprehensive approaches such as the causal loop diagrams which focus on system structure have received attention (Wolstenholme, 1990). Causal loop diagram is an analysis method for system dynamics used for the development of complex, long-term, or one-off projects such as spaceships, computer programs, or offshore plants. International LSPs have similar features of complexity with above projects; hence causal loop diagrams have been used for different LSPs to analyse structural features or project systems. Even if it cannot provide the detailed schedule and cost solution, it can improve the understanding of the project system and provide evaluation of major parameters from the structural perspective.

Figure 2: Design management factor causal loop

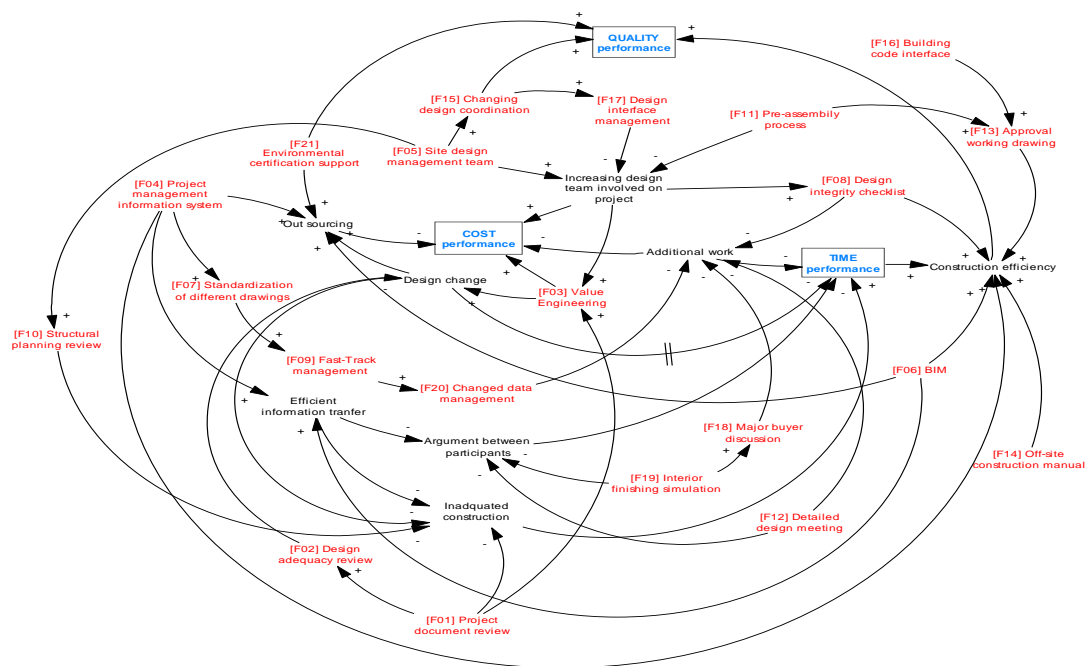


Figure 2 shows the causal loop diagram as a DMD for a LSP, which considers the interrelationship between DMFs. The diagram reflects the cost, time, and quality performance during the production stage. Among DMFs, only two factors (F03, F15) influence project performance directly; F03 and F15 impact on cost and quality performance, respectively. Others mutually influence each other or impact on other dependent elements. By the establishment of a causal loop diagram at early pre-production stage, contractors can establish their design management strategies and substantial implementation plans according to the project performance target. For example, if contractors should reduce the construction costs at a certain production stage, preferentially they can consider the value engineering proposal (F03). This factor is ranked 3rd on importance weight (see Table 1); it also has a direct relationship with cost performance (see Figure 2). However, if there is no specific performance target, contractors may consider the integrated design management team on-site (F05). Even if F05 cannot influence on in any performance target directly, it give impact on quality and cost performance as well as other DMFs at the same time.

## CONCLUSION

Contractors are facing increasing risk and uncertainty on projects caused by complexity. In the Korean construction industry contractors are more responsible for the whole project from design to production; this is of particular importance where international design teams are involved with indigenous local design partners. To manage uncertainty caused by such design-production risk, this research focused on the establishment of the contractor-led DMD from pre-production stage. Through data analysis, collected DMFs were ranked by importance weight and expressed by factor interrelationships. The data was used to establish causal loop diagrams in order to understand the structural features of whole project. Viewing a causal loop diagram can help to provide a comprehensive insight into the fundamental dynamics of the project elements. With this insight, contractors can recognize which DMFs should be considered and implemented as a DMD according to project performance targets and conditions. Such information is very valuable, helping contractors to prepare



appropriate construction methods and to organize resource allocation at pre-production stage. The causal loop diagrams can also be used in system dynamics simulation. Through the simulation, optimal and balanced design management strategy can be established from the contractor's perspective to minimize project uncertainty.

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