The Development of Automatic Module for Formwork Layout using the BIM

Chijoo Lee[1], Sungil Ham[1], Ghang Lee[2]

1 Ph.D. Student, Building Informatics Group, Department of Architectural Engineering, Yonsei University, Seoul, Korea
2 Assistant Professor, Building Informatics Group, Department of Architectural Engineering, Yonsei University, Seoul, Korea
Correspond to Ghang Lee at glee@yonsei.ac.kr

ABSTRACT: Formwork layout is perceived as important due to its strong tie to site works. But, most formwork is done manually and influenced by worker's skill and thus, a lot of construction errors occur. The introduction of BIM (Building Information Modeling) enables acquiring more precise information on the building shape, dimension, structure, etc. than 2D-based drawings and thus, the increased productivity, such as reduction of workload and work times, and the economic efficiency, such as reduction of formwork types and form dimensions with the consideration of constructability, are expected. This study reviewed the previous studies and formwork layout systems to derive this study's differentiations and factors to be first considered for formwork planning were derived by analyzing priorities against consideration factors. Last, a flow chart and algorithm were developed to apply the derived factors to the formwork layout module.

Keywords: Formwork; BIM(Building Information Modeling); consideration factor for formwork layout; module for formwork layout

1. INTRODUCTION

1.1 The Background and Purposes of This Study

Formwork has a great influence on the entire processes of reinforced concrete work and it is a single process that is important from the perspective of construction duration and cost. Thus, formwork has a great effect on the entire construction work as well as following processes[3,8]. Formwork is regarded as an important method to improve productivity in high-rise building constructions around the world. This is because formwork accounts for a lot in construction cost for structural work of high-rise building[6] and has a great impact on shortening construction time by its repetitiveness. In addition, formwork related accidents account for about 5.0% (99 casualties and 17 death tolls) and its risk and danger contribute a lot to the safety on a construction site[9]. Due to the importance of formwork, a number of studies were conducted – especially researches on form selection methods using neural network theory or expert system[3,7,8,10].

The formwork layout is as important as formwork selection in improving productivity. Design on formwork layout influences precise formwork, construction time and site safety. However, there have not been many studies on formwork layout unlike formwork selection. This is because formwork layout requires a lot of manual work and its quantification is difficult due to the influence by workers' skill on formwork layout.

The construction industry is adopting the BIM to provide quantitative information to a number of processes and thus, construction information is transforming into 3D-based information system having actual shape and data. The BIM model can provide a formwork layout system with more accurate data on building shape, dimensions and structure than existing 2D-based drawings. This rationalization of formwork layout is expected to lead to improved productivity, such as reduction of workload and work time, and improved economic efficiency, such as reduced formwork types and rational form dimensions. The existing formwork planning systems, however, only considered form's geometrical shape without due consideration on form types, dimensions and weight, building structure or number of reuse. Additionally, they have not reflected the characteristics of construction site.

The purpose of this study is to develop a formwork layout system for automatic formwork layout planning to contribute to the improved productivity.

1.2 Process and Method of This Study

Figure 1 shows the method to develop automatic module for formwork layout planning, the purpose of this study. First, previous studies were analyzed and then, the differentiations of this study were deduced. Next, consideration factors and their priority for formwork layout planning were analyzed through the theoretical approach to form types and characteristics, previous studies and interview with formwork experts. Last, a flow chart and algorithm were suggested for the automatic layout planning.

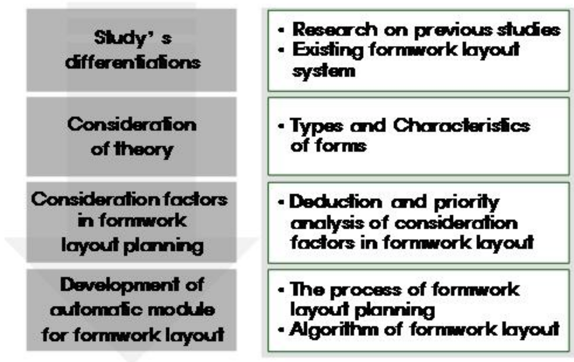

Figure 1. The procedure of the study

2. THIS STUDY'S DIFFERENTIATIONS.

2.1 Research on Previous Studies

As shown in Table 1, previous studies on formwork can be divided into form selection and method, and formwork productivity.

Table 1. Research trends on formwork

classification	author	main contents
Formwork selection	S.G. Kim[7]	Suggest a prototype for decision making support system for the form selection of high-rise building projects in Korea
	T.H. Kim[8]	Develop decision making support model to suggest form selection standards and process
	Y.S. Shin[10]	Select a slab form system suitable for high-rise building projects in Korea and deduce important factors
	Y.S. Jung[3]	Deduce consideration factors for form selection and suggest improvement plans by analyzing the problems in formwork process
Formwork method	D.W. Kim[5]	Suggest a formwork system to shorten construction time of building structure for medium-sized (20-40 stories) wall-type structure
	G.H. Kim[6]	Suggest a new unit table form and analyze its feasibility by studying the result of its application
Formwork productivity	D.H. Kim[4]	Deduce plans to improve productivity by analyzing the causes for system formwork delay and work times
	H.K. Jung[1]	Analysis the productivity of formwork during reinforced concrete work

Decision making model or deduction of important factors was studied for researches on form selection. Kim[7] and Kim[8] presented prototype for decision making support system and model for form selection of high-rise building projects in Korea. Shin[10] studied slab form systems for high-rise building construction and Jeong[3] suggested a new plan after deducing form selection factors. New researches to suggest new systems for formwork method to shorten construction time have been conducted. Kim[5] suggested a formwork system to reduce the construction time and Kim[6] suggested a unit table system. Analysis on productivity and methods for its improvement were conducted for formwork productivity. Kim[4] analyzed the methods for formwork productivity improvement and Jeong[1] analyzed the productivity of formwork. There have been insufficient studies on automatic formwork layout, however. This study deduced consideration factors for formwork layout planning and analyzed their priorities. Then, a formwork layout system that reflects these factors was developed.

2.2 Existing Formwork Layout System

Recent active BIM introductions by architectural design firms and construction companies gradually raised the possibility to acquire 3-dimensional object model information of buildings. Each form manufacturer and supplier currently has formwork layout system for its forms. The existing systems, however, have not reflected unique conditions of each construction site, and the current formwork layouts in construction sites are mostly done by manual work because formwork was developed for simple layout at a designated place and for approximate estimations. Besides, the consideration factors are not reflected enough to the formwork layout planning from the perspective of cost, and because the existing system is structured based on the 2-dimensional drawings, it is too hard to be applied to BIM (Building Information Modeling) to conduct precise estimations or to establish accurate formwork layout plans. This study is to develop a system that can reflect a number of factors which must be considered for an optimum layout, not for a mere formwork layout or estimation for a space.

3. TYPES AND CHARACTERISTICS OF FORMS

Forms are temporary structures to maintain a certain shape and size of concrete in unstable state, to prevent the leakage of water needed for hardening, and to block the influence of air[5], and they must be able to enable concrete's strength structurally required to build a concrete structure with an intended shape and size.

In recent formworks, system formworks are frequently required to be able to secure advanced roles in quality, cost, work time, and safety in construction. Jeong[2] defined system formwork as to manufacture and use them corresponding to the specific purposes according to the characteristics of construction works for the formwork rationalization.

Examples of system formwork include euro-form, gang form, flying form(table form), climbing form, slip form, tunnel form, and traveling form. Table 2 explains the types and characteristics of system formwork.

Table 2. The kinds and characteristics of forms

Type	characteristic
euro-form	This is a modular form, mostly used when the building plan is standardized.
gang form	The enlarged, but simplified forms are assembled and dismantled at a time. It is applied to wall forms.
flying form	It is a floor form, with a form board, a joist, a bean-joist, and a support manufactured and built up as one unit.
climbing form	A form and a scaffold frame for wall finish work are fabricated as one unit, lifted at a time, and installed.
slip form	Vertically and horizontally continuous structure is constructed without construction joints by moving the form continuously.
tunnel form	A wall form and a slab form are manufactured as one unit to construct wall and floor at the same time.
traveling form	It is applied to horizontally continuous structures and supported by a scaffold frame, called 'Traveler.' After the concrete placing of one section, the form is lowered and being moved along with the structure during the layout.

4. CONSIDERATION FACTORS IN FORMWORK LAYOUT PLANNING

4.1 Deduction of Consideration Factors in Formwork Layout

Once the forms are selected to meet the characteristics of site, influence factors on formwork layout like Table 3 must be considered to lay the optimized formwork out. Table 3 was derived through literary review[3,8,10] and interviews with formwork experts and formwork engineers at sites. Among the consideration factors, the primary factors contain cost, constructability, safety, quality, and characteristics of building and site, and each one has its sub-factors. This study is to develop a formwork layout system which reflects the factors presented in Table 3 to the system.

Table 3. Consideration factors for formwork layout

primary factors	sub-factors
cost	kinds and number of formwork types
	number of reuse
	assembling and dismantling cost
constructability	size and weight of form
	workability in continuous work
	workability in curved shape work
	adaptability to the design change
	workability in lifting work
safety	work field manageability
	workers' safety
quality	excellent precision
	securing accuracy in pipe layout/opening positioning
characteristics of building and site	building shape
	characteristics of construction site
	building dimensions
	structural type of building

4.2 Priority Analysis of Consideration Factors in Formwork Layout

The priority when each factor is applied to real site in practice must be analyzed to reflect consideration factors of formwork layout in Table 3 to the formwork layout system. This is to reflect mainly factors of high priority to the system. To derive priority like Figure 2, the priority of primary factors were first derived, and then the weight was assigned to each sub-factor's priority.

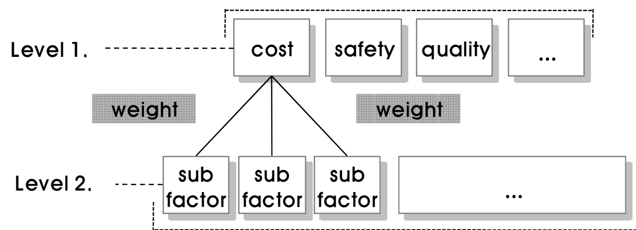

Figure 2. The priority analysis method for consideration factors in formwork layout

To begin with, the priority of primary factors of consideration in formwork layout was evaluated through the interviews with experts at system form companies using the formwork layout consideration factors in Table 3. The priority of the cost factor was evaluated as the highest as in Figure 3, and then comes quality, safety, constructability, and characteristics of building and site in that order.

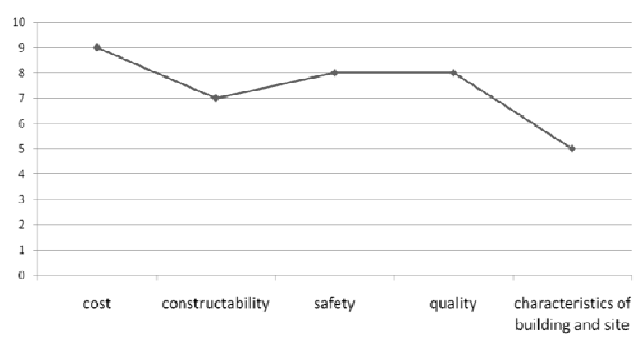

Figure 3. The priority evaluation of consideration factors in formwork layout - primary factors

The evaluation on the sub-factors of consideration factors in formwork layout is as in Figure 4. The priority in precision of quality factor, workers' safety of safety factor, lifting workability and form's size and weight of constructability factor, assembling and dismantling cost and number of reuse of cost factor proved to be high. The priority in structure of building, shape of building, and work field manageability followed.

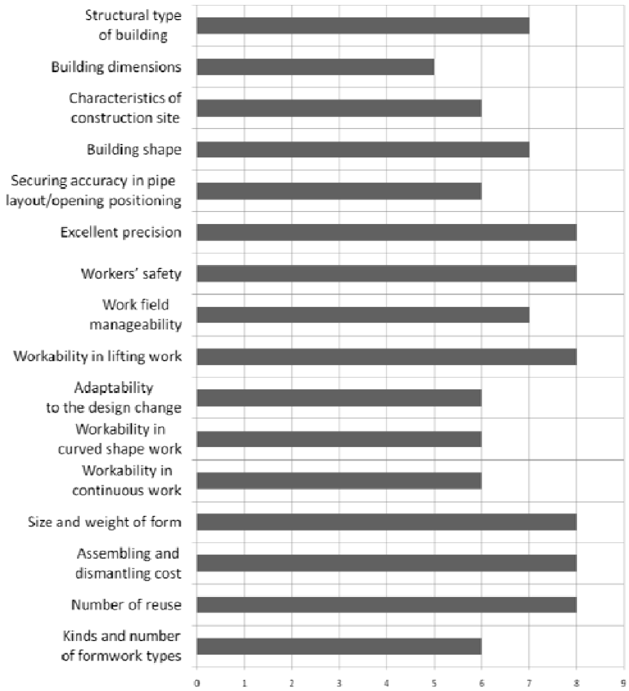

Figure 4. The priority evaluation of consideration factors in formwork layout - sub-factors

As explained in Figure 2, the gross priority was derived by allocating weight of the priority of a primary factor to its sub-factors, and Figure 5 shows the result.

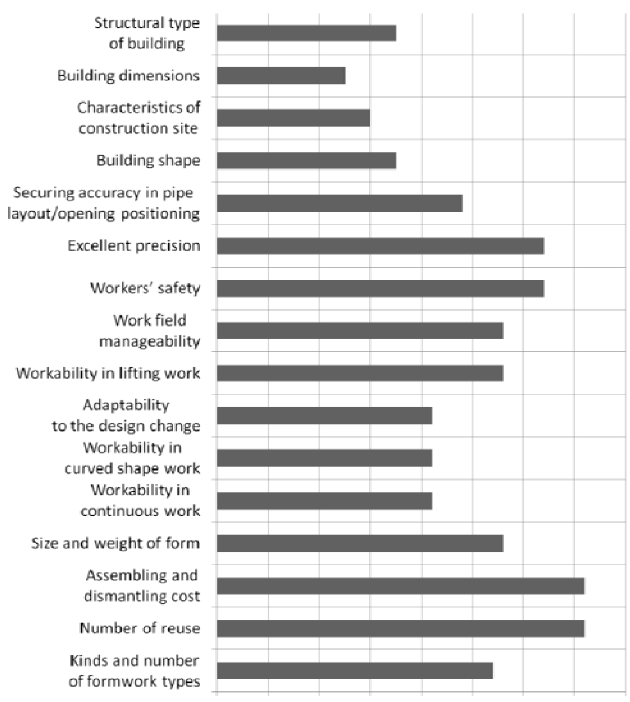

Figure 5. The gross priority evaluation of consideration factors in formwork layout

Among the formwork layout consideration factors, the number of reuse and assembling and dismantling cost had the highest priority in terms of cost factor. The work precision from the perspective of quality factor and workers' safety in view of safety factor followed, and the size and weight of forms and lifting workability in constructability factor, safety of work field management in safety factor, and the type and number of form classes in cost factor were high in their priority. Through this, the primary consideration factors in laying the forms out are generally sub-factors in cost, quality and constructability.

5. THE DEVELOPMENT OF AN AUTOMATED FOR FORMWORK LAYOUT SYSTEM

5.1 Algorithm for Automated Formwork Layout

Among the consideration factors in Table 3, those quantifiable for the formwork layout system were primarily to be reflected to the system, and Figure 6 shows an algorithm for formwork layout system.

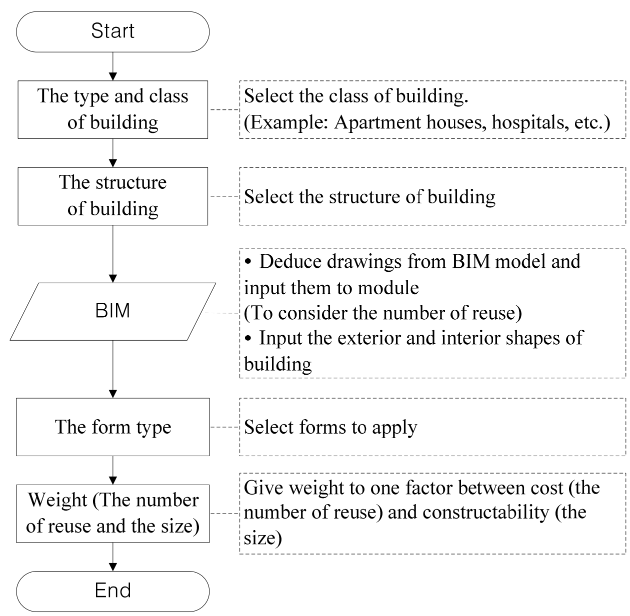

Figure 6. The Algorithm for automating formwork layout

Detailed information like the size of building, and interior · exterior shapes for the formwork layout system developed in this study was supplied not by existing 2-dimensional drawings, but by BIM (Building Information Modeling). The reason is for precise estimation and less construction errors to enhance the accuracy.

The algorithm of formwork layout is shown in Figure 6 is as follows. The class and type of building are selected in advance because the requirements and the type of forms are dependent on them. After the structure of the building for the application is selected and the structure strength is taken into consideration, drawings are deducted from BIM and inputted to reflect the floor size of the building to which forms are applied. Once the surface where forms are to be installed, geometric characteristics of the surface and the area and the characteristics of the surface are automatically analyzed. Then, the building's interior · exterior shapes are received from BIM, and when the size of forms is selected and the forms are laid out, it is decided whether or not weight is given to the number of reuse in view of cost and the size of forms in terms of constructability. The shape of building is inputted as a final process. Through this, the total size and model of forms are decided using the forms that users want, and the forms are laid out on the selected surface over the 3D screen.

5.2 Implementation of a Formwork Layout System

A formwork layout system was developed as a Windows OS-based independent application using .NET framework and Vectordraw CAD components based on the layout algorithm shown in Figure 6. Independent applications have advantages that they can be used for general purposes without depending on a specific CAD program like other plug-in types and have scalability. The application in this study adopts 3-dimensional graphic user interface (GUI), enabling automatic formwork layout, and its confirmation and modification on 3D screen, and it can be used to apply drawings and information produced by using BIM (Building Information Modeling) to a formwork layout system.

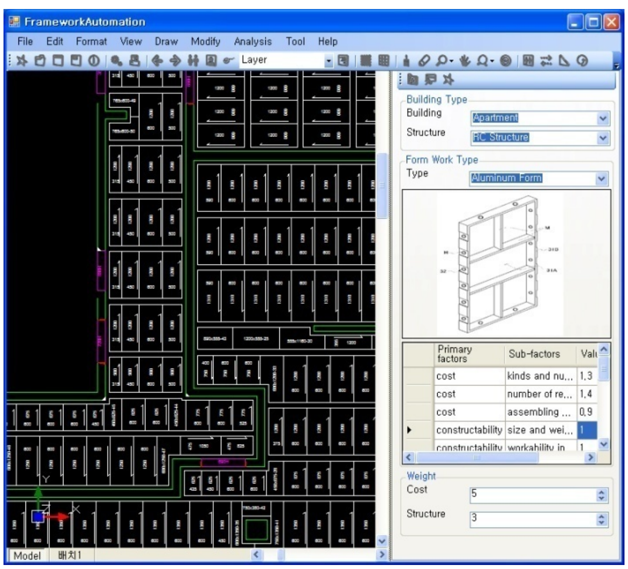

Figure 7. A newly developed formwork layout system

6. CONCLUSION

The matters such as construction productivity improvement and decision making process change caused by BIM (Building Information Modeling) have recently become an issue in construction industry. To cope with these changes, this study developed a system for formwork layout planning which was usually done by manual work and dependant on site workers' experiences. The major conclusions can be categorized as two: the deduction and priority analysis of consideration factors in layout planning and development of a formwork layout system. First, the consideration factors for formwork layout were derived as five primary factors, such as cost, constructability, safety, quality, and characteristics of building and site, and sub-factors of each primary factor through existing literary research and expert interviews. Next, factors to be first considered for formwork planning were derived by analyzing priorities. The number of reuse and assembling and dismantling cost with the perspective of cost factor, workers' safety in terms of safety factor and precision in view of constructability factor turned out to have high priority. Secondly, a flow chart defining information input and process was produced to develop a formwork layout system. An algorithm was developed based on a quantitative analysis of consideration factors in formwork layout. Based on the algorithm, a formwork layout system was developed. The limitation of this study is that it is difficult to apply the developed cost-based formwork-layout algorithm to atypical buildings whose number has been increasing a lot recently.

Future study will complement the formwork layout planning module in this study, and test its economic feasibility and effectiveness by comparing to the actual formwork layout planning used for the completed buildings.

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