Master's Science in Engineering

Lifting Planning Decision Support Model for the Mid-to-high-rise Modular Construction

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Abstract

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Modular construction is a construction method with the production work in factory and the installation work in field. Especially the lifting work is a large part that requires for the installation of modular units in the field work. The exact lifting work forecast in the initial phase of the project lead to calculate the optimum construction period and cost.

However, existing lifting equipment selection is performed on the intuition and the experience. So, there is a need for the objective and logical lifting equipment selection tool. In this study, proposed a model that can be the selection of the optimum of the tower crane through the relationship of three variables(tower crane, installation module unit and transport trailer) that affect the lifting work. For this reason, the methodology of this study uses a genetic algorithm that is effective to find combinations of many variables, site of the mid-to-high-rise modular building coordinated. In order to verify the validity of this research, conducted a verification on a modular project to be done in the future.

Through the genetic algorithm, confirmed the capacity of the tower crane and the position of the tower crane and the trailer for transporting the modular unit that has the minimum lifting distance and satisfies the required lifting height. In the future, used in a modular building project to sharing information between the designers and constructor in the early stage of the project, can help make the optimum lifting plan.

Keyword : Modular construction, Tower crane, Lifting planning, Mid-to-high-rise construction, GA(Genetic Algorithm)

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Chapter 1. Introduction

1.1. Research Background

The modular construction differs from existing construction methods such as shorter construction period, economical efficiency, environmentally friendly construction method, which is different from the construction work done in the construction site, through the factory production(Kim et al., 2014). With these features, modular buildings are applied to various buildings such as detached homes, dormitories, small rental houses, Mid-to-high-rise residential buildings(Jung et al., 2015). In Korea, the modular structure is primarily five layers' building or less. However, outside the country, it makes 15 layers or more high. It expected widely use with the modular structure.

The contents of the modular construction decided at the design stage are the scale of the modular building, the installing order of the units, the type of the unit, the connecting method and the production rate at the factory and on site, etc.. It is an important factor for both the manufacturing process at the factory and the installation process at the site later. The point to be noted when designing a Mid-to-high-rise modular building unit is that it must match the conditions of the site(building laws such as the border line of lot, whether access by trailer for transport the modular unit is possible, whether the construction site that the crane can’t lift and move) where the modular unit will be installed and it must be able to be hoisted with a pre-determined lifting equipment. If the prediction of these conditions is not correct, additional equipment has to be inserted or redesign becomes necessary.

As described above, the lifting plan is a core element that forms the basis of the whole construction plan, and an incorrect lifting plan brings inefficiency of the entire construction, causing an increase in the construction cost and time(Kim et al., 2002). However, there are many difficulties in lifting plans for high-rise buildings. Since lifting plans are primarily formulated by experience and intuition without applying a systematic method, there are problems such as increasing the transportation cost, losses such as utilization of inefficient resources are occurring(Chae, 2002).

Especially in the case of mid-to-high-rise modular construction sites using tower cranes which are difficult to move after initial installation, unlike low-rise modular building sites mainly using mobile cranes. If the lifting conditions are changed for alteration in the design and the field conditions, additional equipment casting and installation time of the tower crane is necessary. In addition the construction time and cost may increase. In order to prevent this situation and minimize, the lifting plan progress at the design stage in parallel(Figure 1-1). For these reasons, it is necessary to develop an model to lifting equipment selection tool with accurate lifting work prediction at the initial design stage of moderate to high-rise modular projects for calculate optimum construction costs and time, utilizing information on building scale, ground conditions, tower cranes, transportation trailers, etc..

Moreover, examination of lifting plan of modular construction which is different from the general construction upgrade plan must be accompanied. In general construction, the main points of lifting the tower crane are the point to start lifting(P1) and the lifting in the final destination where the lifting finishes finally(P2). In general construction, if the size of the lifting target is too large or the weight is too heavy, it is possible to increase the number of times or reduce the size to lift, so the location and capacity of the tower crane are selected, only the destination of lifting(P2) is mainly considered as an important factor. However, there are problems in applying the same method as in the case of the modular construction, as the main target of lifting is a modular unit that can not be separated in small units. In the case of modular construction it is impossible to separate, since the completed finished product needs to be lifted, the start point of lifting(P1) is fixed to the destination of the trailer which finally moves the unit. Therefore, in the modular construction, a lifting plan considering both the start point of lifting(P1) and the destination of lifting(P2) is necessary.

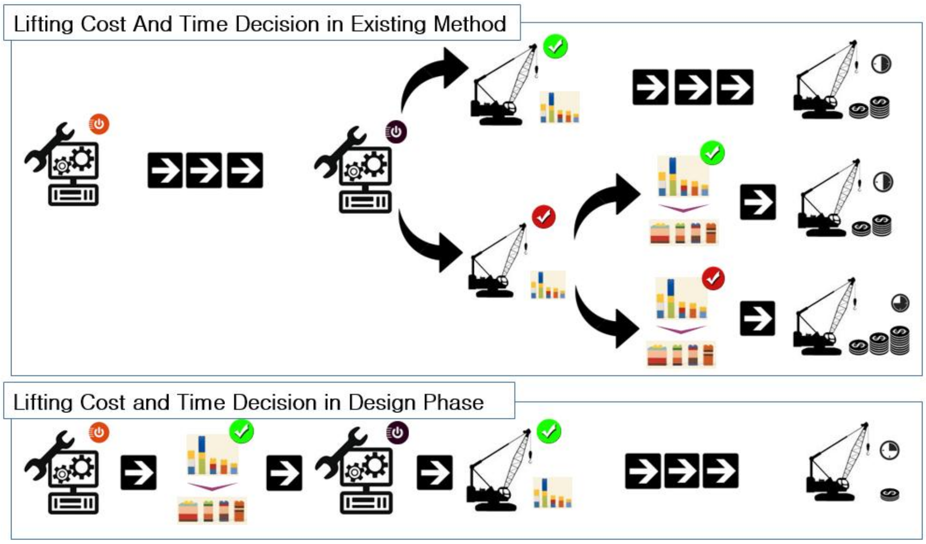

Figure 1-1. Comparison With Result of Phase Change in Design Process of Lifting Equipment(Adopted from Ho et al., 2007)

Therefore, in this research, developing a model to confirm the tower crane capacity and the optimum position of the tower crane / modular unit transport trailer, of the moderate to mid-to-high-rise modular building project. And It is aimed at developing an optimal tower crane selection model according to the relation of each element that is necessary for selection of lifting equipment such as tower crane, modular unit, transport trailer.

The result of this research is utilized as a tool of communication for the designer and constructor through information exchanges at the time of selecting the position and specification of lifting equipment at the initial stage of design at the time of mid-to-high-rise modular construction project later on.

And it can be used as a basic tool for forecasting the construction cost and time.

1.2. Research Objective and Scope

In this research, suggesting a model that can help the designer selects the heavy machinery that is necessary for the lifting work on the site work of the modular building using limited information of the project at the initial design stage. And the model which derives through the relationship between the variable that influence the lifting distance which are the lifting equipment, the trailer and the modular unit that will be installed to the site.

At this time, the research is aimed at the mid-to-high-rise modular building that is over 15th floor where the use of a tower crane is inevitable.

1.3. Research Procedure

The order of this research is as follows

1) Research on the studies of selection of tower cranes for modern mid-to-high-rise building construction including the modular construction. In this stage, analyze the existing researched literature, confirm the lifting process of general construction, and discuss the lifting planning method suitable for the modular construction.

2) Using a genetic algorithm(GA), developing an optimal tower crane selection model for the mid-to-high-rise modular construction. For that purpose, conducting preliminary research on genetic algorithm, and plan to develop a model to derive the location and capacity of the tower crane using genetic algorithm and the location of the trailer moving the modular unit. The model development process will explain the overall structure of the model and model virtual building site, input factors, process of the model, and output explanation. Based on this, preparing for the next stage, applying on the actual site.

3) For application of cases, progressing the feasibility research through comparing the results of the model with the existing arrangement plan in case study. The construction used as an example is Prefabricated apartment test site construction(assumed name) that will be done. Based on the arrangement of lifting devices described in the existing construction project document

confirmed what kind of results can be obtained by comparing the lifting equipment through driving of the model and the ophthalmology of the model, and the contribution of the model. The flow of research including the method, the scope and the order of research are as shown in the following(Figure 1-2).

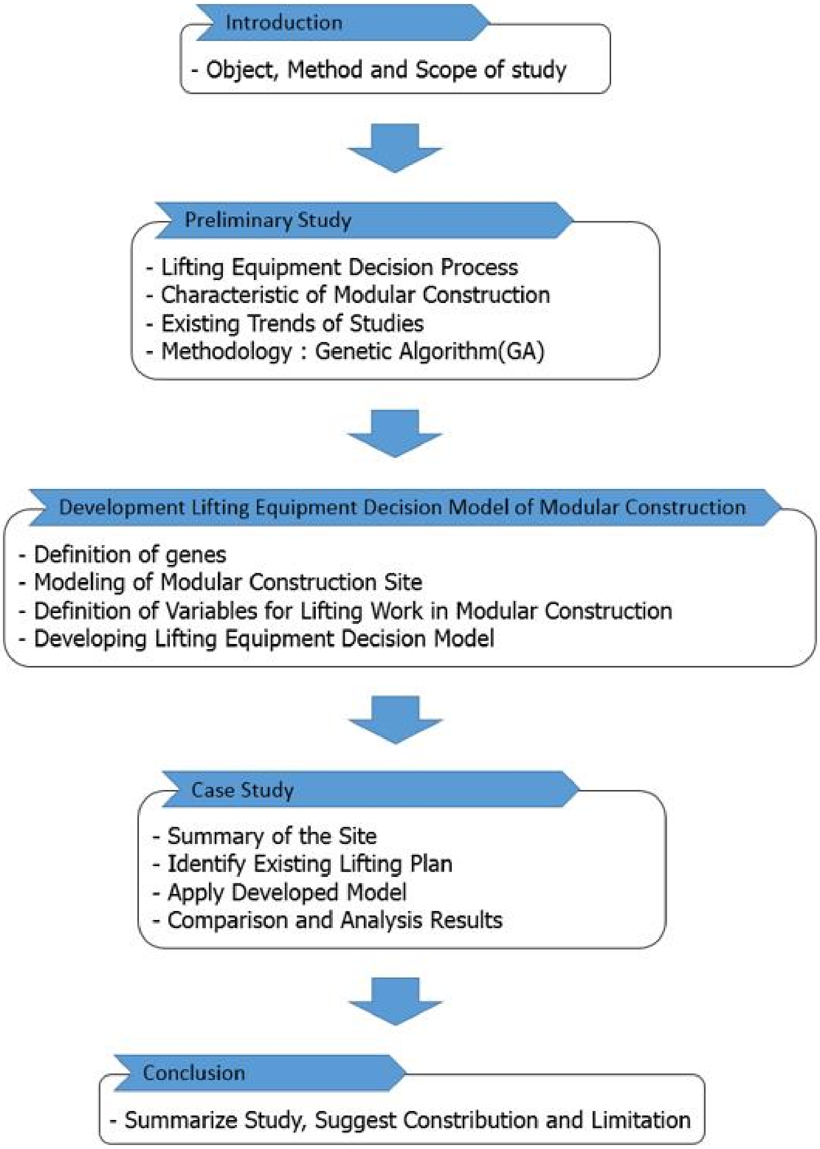

Figure 1-2. Research Process

Chapter 2. Preliminary Study

In this chapter, contents of preliminary studies for a lifting equipment selection model of the mid-to-high-rise modular construction are described. In detail, the selection process of lifting equipment for general architecture, studies for lifting by researchers and the use of Genetic Algorithm as a methodology for this study were confirmed.

2.1. Lifting Equipment Selection Process of the Modular Construction

The process of general construction projects will proceed largely in order of bid - design - construction - maintenance. Among them, at the design stage, it is a very important factor that determines the success or failure of the construction project as a whole. So the importance of this phase is high(Oh, 2004). At the stage of architectural design, it is classified into Schematic Design, Design Development and Working Design Stage, the design process of modular construction also does not different to that much. As with the process of the general construction project, selection of the lifting equipment of the modular construction is carried out by the "constructor" after the Working Design is completed.

However, unlike lifting work in general construction, there is a difference with the modular construction. In the case of general construction if the heaviest weight material for lifting is heavier than the capacity of lifting equipment, consider dividing the weight of a single lifting weight to the light material that can be lifted twice or more. And use another lifting machinery at the work site such as the hoist, etc. Conducting Resource Leveling can change to another lifting plan(Figure 2-1). However, in modular construction, these methods can’t be carried out. Because in modular construction the target of lifting is the finished modular unit that can’t be divide.

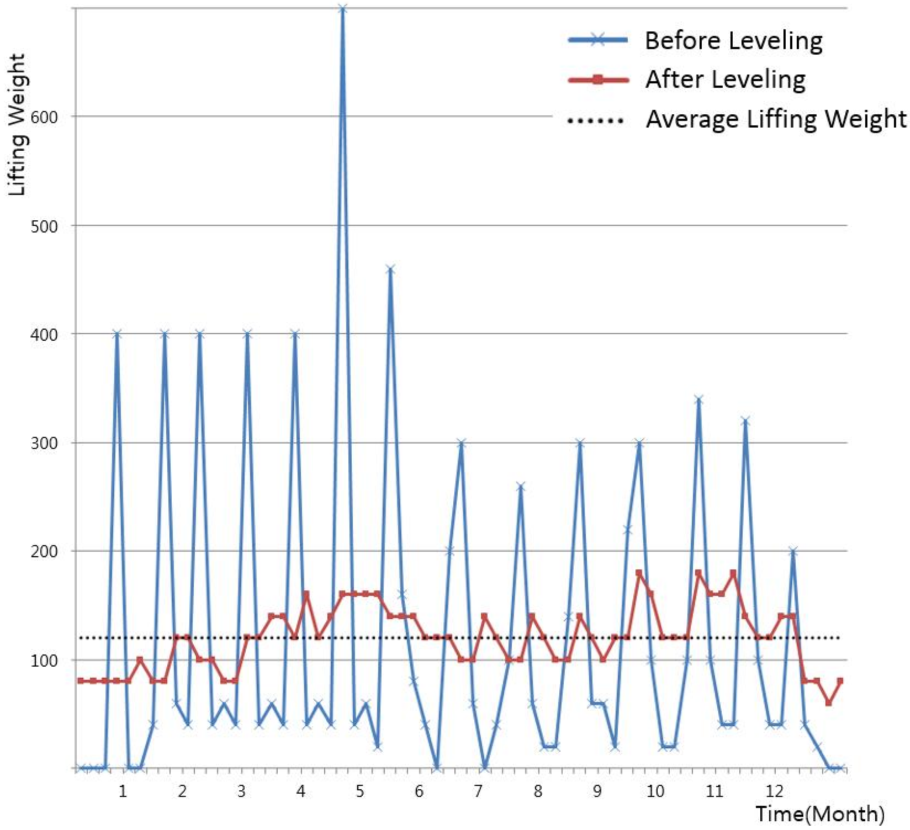

Figure 2-1. Comparison Before and After Resource Leveling Lifting Load(Adopted from Lee et al., 2014)

Therefore, the selection of a lifting equipment in the modular construction is an important factor for lifting work at the site. And this is a factor that greatly affects the construction time and cost. However, as mentioned before, since the selection of lifting equipment is decided after Working Design Phase is completed(Figure 2-2), When fluctuations of the lifting equipment occur, it is difficult to handle quickly. For this reason, it is necessary to have a model that can coordinate opinions between designers and constructors concerning selection of lifting equipment during the initial stage of design.

In the research of existing crane selection, confirming the elements and the procedure for deciding the crane at the construction site. And confirmed that the lifting plan recognizes it as an important factor directly affecting the construction time, safety control and construction cost etc.

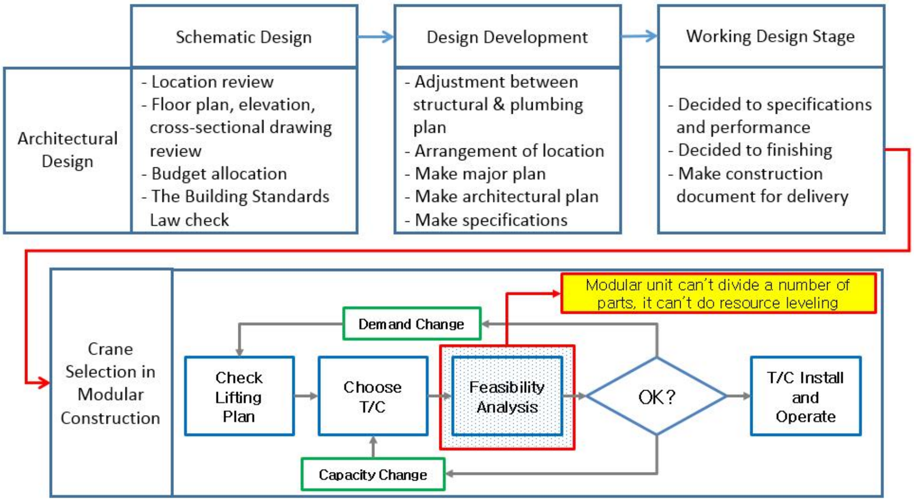

Figure 2-2. Role of Design Phase and Tower Crane Selection Process(Adopted from Ho et al., 2007, Chun et al., 2003)

Studies of the crane selection can be categorized into crane type, size of building, number of cranes and research content. In case of the optimization according to position and lifting time, it can be divided into analyzes a mathematical model and genetic algorithm(Table 2-1).

Table 2-1. Crane Selection-related Research

Crane type	Bldg's height	No. of crane	Results	Author
Tower	High -rise	Multiple	Developing mathematical models that can check the shortest possible travel time of the crane hook	Zhang et al. (1999)
			Development minimize lifting time point confirm model by lifting time analysis	Leung & Tam (1999)
			Based on the site conditions, work planning and equipment efficiency T/C selection model development	Lee et al. (2002)
			Development lifting planning system based on the lifting time	Kim. (2003)
			Crane selection model developed considering the crane stability and working conditions	Ho et al. (2007)
			Development location optimization model with GA multiple lifting equipment and material stacking	Kim et al. (2009)
			Based on 6 Sigma, T/C selection process analysis and selection algorithm development	Cho et al. (2009)

Crane type	Bldg.'s height	No. of crane	Results	Author
Tower	High -rise	Single	Developing a mathematical model that have minimum material transfer time	Joo et al. (1994)
			Minimize development costs lifting points finding models using GA	Tam et al. (2001)
			Development shortest lifting range checking model with the GA	Lee et al. (2004)
		Single, Multiple	Confirm tower crane's adequacy location through case studies	Lee. (1998)
Tower, Mobile	High & Low rise	Single	Development model that find optimal radius of a crane position with through a mathematical study	Rodriguez et al.(1983)

Zhang(1999) conducted research on supposing the use of multiple tower cranes for a mathematical model that takes into consideration the moving time of lift materials that calculated the movement of the hook of the tower crane.

Lee Hyun-Soo(2002) examined the place where the tower crane can be installed as part of the planning process for the high-rise building. At this time, the planning process of the tower crane was divided into the combined generation process, the alternative generation process and the evaluation process of the alternative plan, but it is unsatisfactory not to apply to the actual case.

Lee Woong Kyun(2004) presented a model using genetic algorithms focusing on reinforced concrete framework construction.

Ho Jong-Kwan(2007) is developing the optimum tower crane selection system that can be used at the lifting stage of the high-rise construction and examined the stability of the crane.

Kim Kyung-ju(2009) conducted a research on a model to simultaneously optimize multiple tower cranes and material placement positions using genetic algorithms.

Rodrigues(1983) established a selection model of a lifting equipment for the position confirmation of a single tower crane using a mathematical model.

Joo Jin Ho(1994) conducted research on location selection used for the high-rise building through analysis of the lifting location and moving time of the materials project.

Lee Yol(1998) studied the minimization of the period of using tower crane for the steel-frame work in high-rise construction sites.

Leung(1999) suggested a reasonable lifting time prediction model through analysis of relationships of elements related to the lifting plan.

Tam(2001) conducted research on the selection of a single tower crane position considering the moving time of lift material according to the specification of a tower crane, using a genetic algorithm.

Kim Jung-Jin(2003) established a lifting plan utilizing the actual cycle data of the materials applicable to the skyscraper construction on the 30th to 70th floor.

Finally, Cho Ji-Hun(2009) analyzed optimizing the position selection of the tower crane suitable for the skyscraper characteristics through the study of the lifting cycle time based on the 6 sigma method.

As a result of the analysis of the previous research, it was possible to confirm that the lifting plan, which generally selects the position and specification of the crane, is to be performed after the design process is over. However, in the case of a modular project, the lifting equipment selected by this method, problems such as an increase in the construction period and additional arrangement of lifting equipment can occur when equipment suddenly encounters a problem, such as an increase in unit lifting, etc..

As a method for solving these problems, although it is possible to apply the DB(Design-Build) method to the modular project. Working with more participating organizations(including designers and constructors) than general construction work, organizations involved in each task are also not involved in one organization but many organizations are involved(Chun, 2005). This is due to the characteristics of the DB system which can address the possibility of design errors possessed by modern construction projects showing a very complicated configuration and form as compared with the past(Lee et al., 2007). Also, unlike general construction, in modular construction, the trailer must also be considered as an important element of lifting. Because the modular unit being used directly from the trailer for transportation. For these reasons, when applying the method presented in the existing previous research to modular construction, there is a limitation that the reflection of the site conditions can be limited.

In addition, consideration of a trailer for moving a modular unit, which was proposed from Chapter 1, is excluded, and consideration on this part is necessary. Modular construction has a difference with the lifting plan of general construction, this is related to the trailer responsible for moving the modular unit. In general construction, if the scale of the lifting target is too large or the weight is too heavy, since it is possible to increase the number of lifts or reduce the size and lift it, the location and capacity of the tower crane, plan a lifting plan mainly considering the destination of the lifting as an important factor. However, in the case of modular construction, there is a problem with applying the same method, because the element of lifting is a modular unit that can not be separated in small units. In the case of the modular construction it is impossible to separate, as it is necessary to lift a finished one finished product, at this time the starting point of the lifting will be the arrival point of the trailer moving the unit. Therefore, in the modular construction, a lifting plan that takes into consideration both the starting point of lifting and the destination of lifting is necessary. However, since the preceding research mentioned only the general construction plan of the construction, it is judged that it is difficult to apply to the modular construction as well.

Also, one of the modular building lifting work's characteristic, compared to general construction work, there is a feature that it is necessary to withdraw heavy objects and to withdraw in heavy objects in order of stacking(Shin et al., 2015). And confirm the characteristic that it must structurally resist side force by using lateral force resistance system such as RC core(Hong, 2014). Therefore, taking into account these points, the location and capacity of a tower crane in a moderate to mid-to-high-rise modular building project must be chosen.

In this research, in order to prevent the occurrence of these problems in advance, developing a model that can find the capacity and the position of the tower crane to minimize the distance between the crane's maximum weight object and the tower crane.

2.2. Genetic Algorithm(GA)

The genetic algorithm(GA) is a navigation algorithm for solving the optimization problem by applying the principle of evolution, this applies the process of evolution that survives only the object most suitable for the environment in nature. It is implemented in the form of evolving genes through processes such as selection, crossover and mutation(Figure 2-3).

Therefore, it is suitable for problems to find a combination of various variables through relations of these variables, so it is applied positively to combinatorial optimization, scheduling and transport problems(Kim et al., 2015, Han et al., 2008, Kwak et al., 2014).

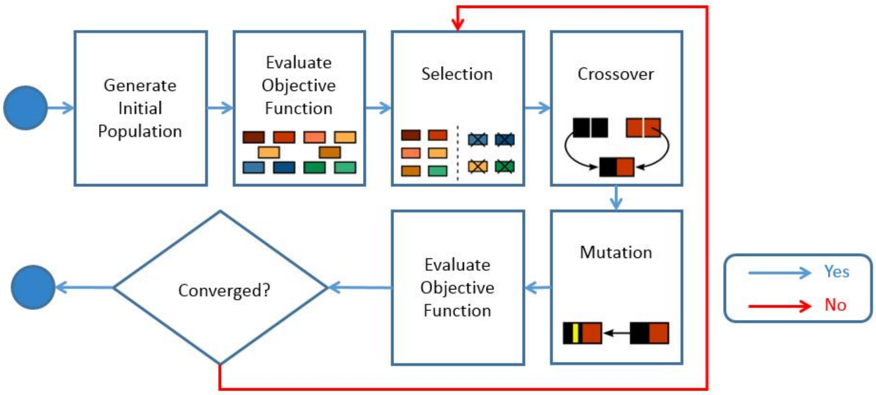

Figure 2-3. Process of Genetic Algorithm(Adopted from Jade Chung' s homepage)

The specification of the tower crane which is the object of this research is changed according to the lifting weight which varies according to the distance between the tower crane and the lifting object(the modular unit in this research). Since this variations according to the distance of the crane-modular unit and crane - trailer, tower crane installation location, modular unit installation location and the position of the trailer that moves the modular unit are factors that affect the specification of the tower crane.

Therefore, there is a need for a method that can correlate and optimize a large number of variables for deriving the position of the above three factors, applying genetic algorithm as methodology that can find the optimal combination of variables in research.

2.3. Summary

In this chapter, investigated the process of selecting lifting equipment in the modular building process and the genetic algorithm as methodology of this research. The process of a general construction project is carried out in order of bidding-design-construction-maintenance, the design stage, as the first step of the overall construction, it is an important step that has a significant influence on the next step. It is done in the same process in modular construction. especially the lifting plan which greatly influences on-site work was built by the constructor after the design process was over. Therefore, confirmed at various studies on crane selection, but the research for modular characteristics is still needed. The methodology of this study, genetic algorithm was used to solve the optimization problem by applying the evolutionary principle. Because it is suitable for the problem of finding the combination of various variables that affect the specification and the location of the tower crane.

Chapter 3. Model Development

In this chapter, developed a model that used the genetic algorithm for selecting the location and specification of the tower crane, which is the object of this research. First, in order to apply the genetic algorithm convert elements used for the lifting work of mid-to-high-rise modular projects to the chromosome, the virtual site is gridded. And the result value is derived through a process. The framework of the model that derives the results of this study is as follows(Figure 3-1).

First of all, after defining and inputting input factors, select the location of the tower crane and the modular unit moving trailer using genetic algorithm. Since then, checked whether selected a tower crane that satisfied the criteria such as longest distance, the weight of the heaviest weight, through comparison of self-reliance height and the height of the building. If the derived tower crane does not satisfy the given conditions, the lifting itself will not be executed, so progress can be made unless other results are obtained, as a result derived earlier through the genetic algorithm, repeat the process of obtaining for better results. Next, compare the rental fee of the tower crane that satisfies the conditions, select the priority order, and make basic materials that the person in charge of work can decide. In this case, by offering three or more results which do not provide one result, the choice range is widened so that flexible selection according to the situation can be made possible. In chapter 4, the validity of this model is further confirmed by comparing the contents with the construction plan of the actual site.

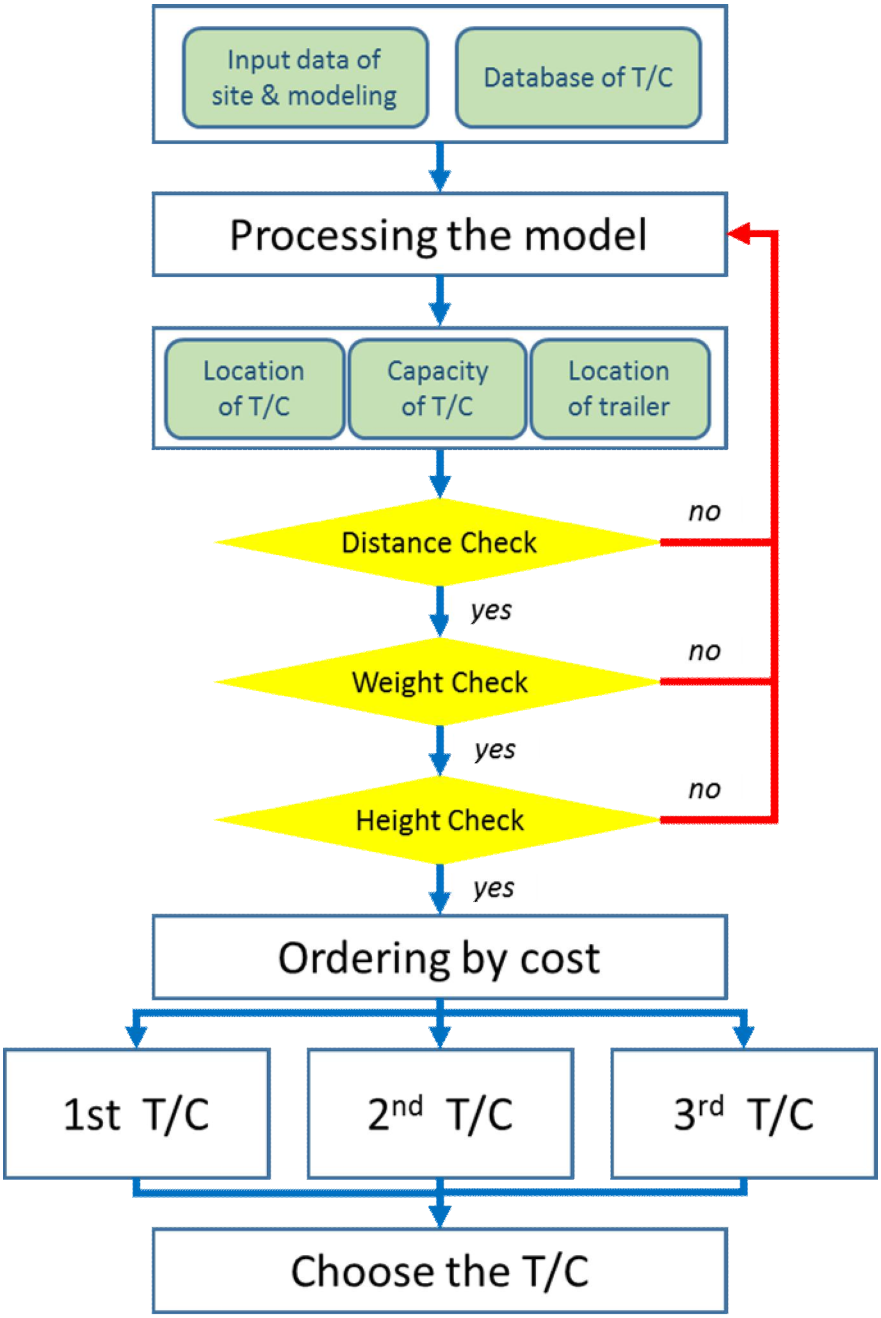

Figure 3-1 The Framework of the Model

3.1. Model Configuration

The model proposed in this research is structured with the aim of selecting the location and capacity of a tower crane of a mid-to-high-rise modular building to be performed in the downtown. So that, input the information of the input factor and the DB of the tower crane, which are related factors of the model, by reprocessing the information through investigation. After that the selection of all the tower cranes that can be worked through checking the distance between the elements in the project, self-reliance height, and tip load of the crane. In this result, aiming at outputting priorities based on the rental fee. In order to drive the model, the installation position of the modular unit was preliminarily input as a constant at the initial configuration of the model, and the installation position of the tower crane and the placement position of the trailer were confirmed via a genetic algorithm(Figure 3-2, 3-3, 3-4).

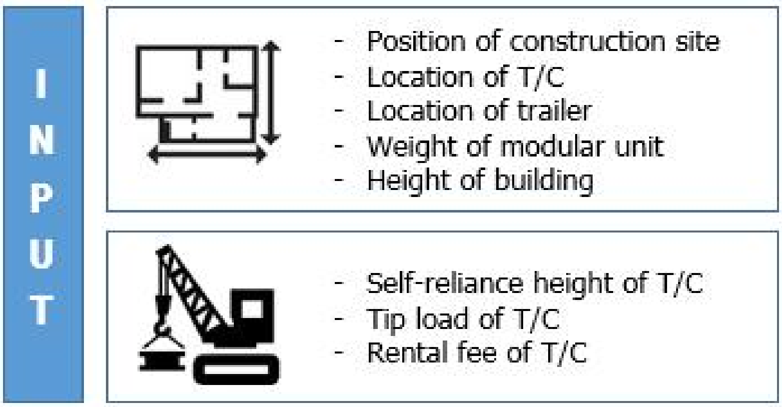

Figure 3-2. Input Level of Model

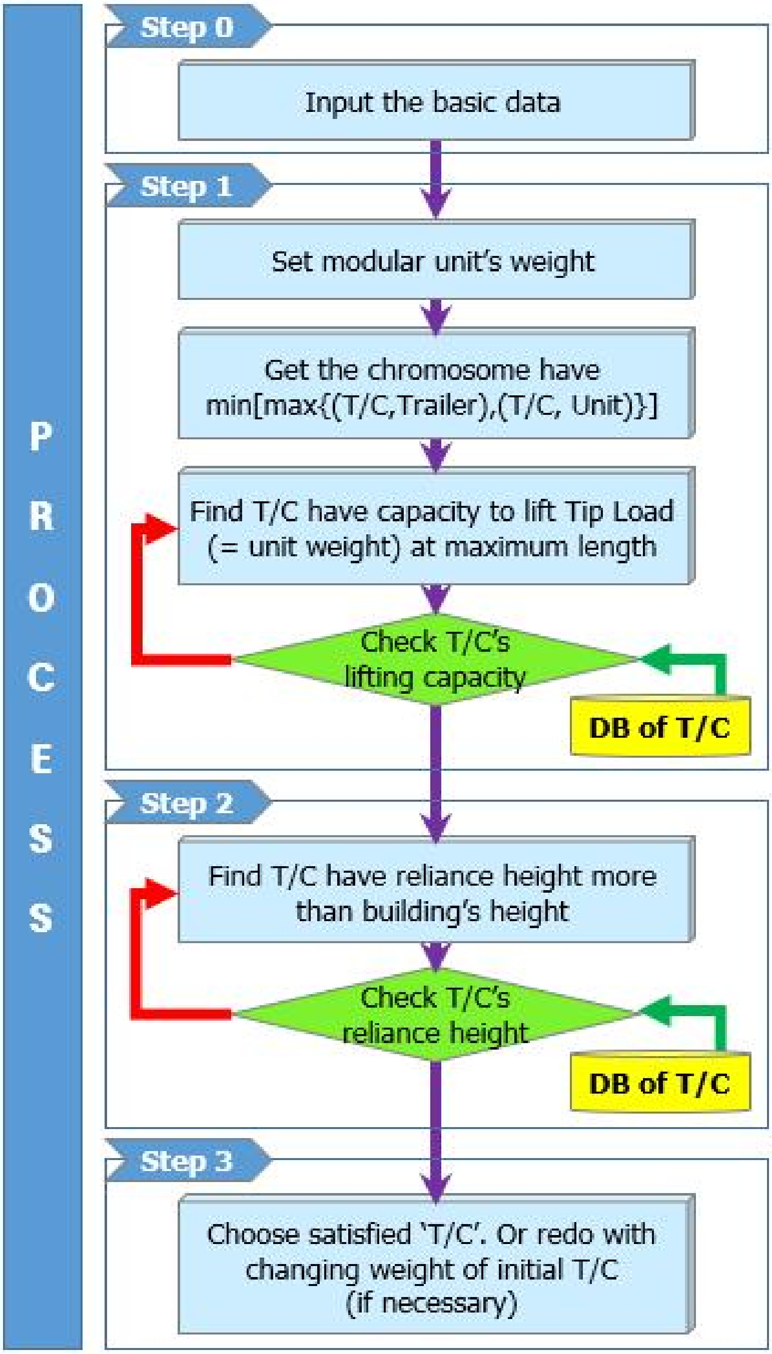

Figure 3-3. Process Level of Model

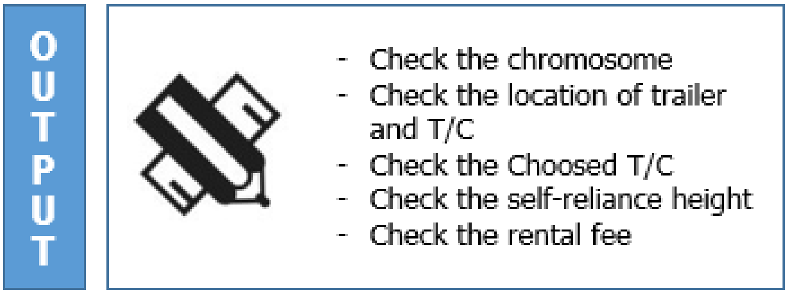

Figure 3-4. Output Level of Model

3.2. Construction Site Modeling

The first thing need to do to construct a model is to embody it so that you can model parts of the building project. The first thing to do is to model the building site so that it can coordinate. As seen in the structure of the model, coordinating the construction site is a basic element for selecting the placement position of the construction factors(the modular unit to be installed, tower crane lifting for modular unit, and modular unit transportation trailer) in the building site to be performed at a later. To that end, it is necessary to model of the actual building site, and create an environment that can match the construction conditions of the construction under construction as much as possible.

The construction project assumed in this research is a building of a mid-to-high-rise modular construction that performed in the downtown of the city. In order to apply the model of the genetic algorithm the most building site must be coordinated. At this time, the interval of the grid in the construction site was assumed to be 0.5m, the reason is that the standard of the modular unit mainly used at the current site is using various standards such as 3m × 6m, 3m × 9m, 2m × 6m, when checking the center of gravity for lifting this modular unit two-dimensionally, 0.5m becomes the minimum unit, decided the grid interval is 0.5m. Also, in this model, assuming it is adjacent to the carriageway, construction of a downtown area where the use of the area maximizing site's efficiency is important, the modular unit transport trailer should be limited to impossible to locate in building site(Figure 3-5). After completing the modeling of the construction site in this way, it is possible to proceed to the next step.

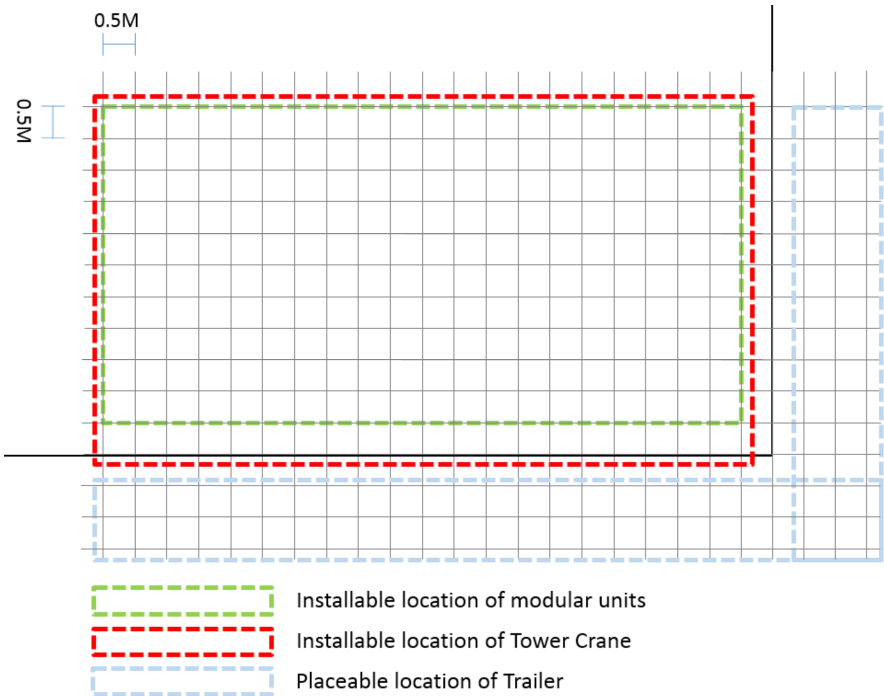

Figure 3-5. Modeling of Modular Construction Site(Example)

3.3. Lifting-related Input Factors

In the next step, enter the characteristics of the lifting-related factors that directly perform the lifting work immediately. The relevant elements entering the model the database are input factors, variables, and database of tower crane. First, input factors are site information on the construction site where the mid-to-high-rise modular structure enters. At this time, as mentioned above, since assumed a construction project within the downtown in city, distinguish and organize the site where the modular unit is installed and the road area where the transport trailer is placed. Due to various site conditions, impossible to install a modular unit, impossible to install a tower crane, and impossible to place a trailer, excluding the possibility of not entering, increase the accuracy of the model. Next, a variable for position selection of lift-related elements, these variables can be divided into three roughly.

The first element is a modular unit that will be install on the pre-determined building site, in this model, assumed that it is possible to install in all the sites in the building sites, consideration will be given to all parts of the sites.

The second element is the installation site of the tower crane which lifts the modular units. assumed that it can be installed on all construction sites, consideration will be given to parts in all of the building sites.

The last element is a transport trailer that transports the modular unit, assumed construction in the downtown where there is not much free space, that can’t be placed in the construction site, set the position of trailer is possible nearby carriageway.

What to enter next is about the information of the tower crane referenced in the model. In the database of tower cranes that used for lifting work, various specifications of tower cranes are included. This includes tip load, self-reliance height and rental fee of tower crane, which are elements that directly affect the lifting work of mid-to-high-rise modular building during the course of research. This database will be used as a basic information for selecting a lifting equipment that is the result of the developed model for required conditions for lifting(Figure 3-6). Especially change of tip load of tower crane due to changing lifting weight and rental fee of tower crane will be an important factor in performance comparison, so enter via accurate preliminary investigation. Detailed explanations of input factor and tower crane database are described in Appendix A.1, A.2.

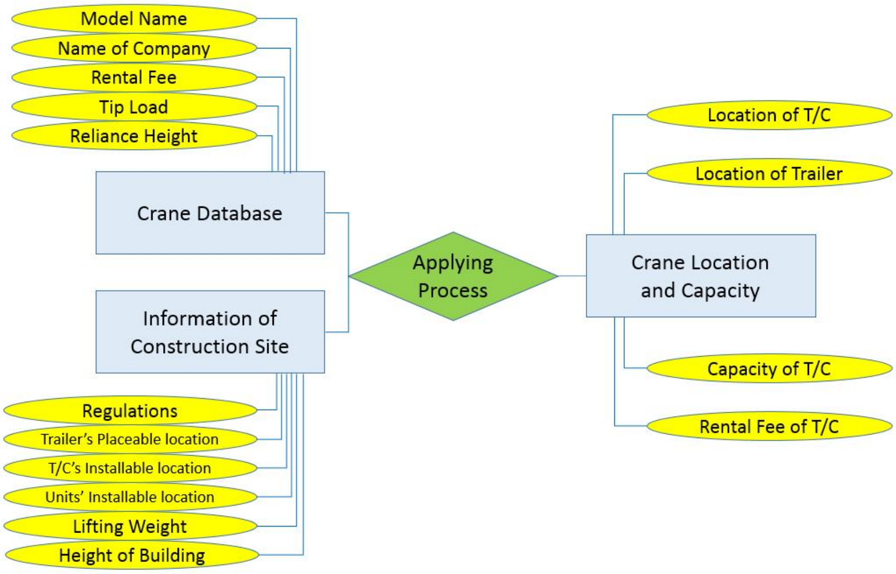

Figure 3-6. Entity-Relationship Diagram of Model

3.4. Site Information Conversion Used in GA

After preparing up to the above steps, need to do is just to place the tower crane and the modular unit moving trailer. Placing these two factors has numerous cases according to the conditions of the construction site, but the method used to solve is the genetic algorithm that above-mentioned. In this research, analyze the position of the tower crane and the modular unit transport trailer according to the position of the modular unit installation location at the mid-to-high-rise modular construction site using the genetic algorithm. In order to do this, the coordinate work of the site information, beforehand work must be proceeded so that an arbitrary value can be placed on the construction site where there is a possibility of arrangement of this factor. For this reason, convert the above variables so that they can be used to chromosomes to apply to genetic algorithms. Therefore, the length of the chromosome(P) is defined as the sum of the place where the tower crane can be installed(P_c) and the place where the transport trailer can be placed(P_t), The gene is defined as the number of tower cranes located at the target location(Figure 3-7).

For example, when the tower crane is located at P_x, the gene is expressed as "1", The position of the tower crane is not located, the gene is expressed as "0". In the same way, when the transport trailer is located at P_x, that gene is expressed as "1", The position of the trailer is not located at P_x, that gene is expressed as "0". In this study, since assumed the use of a single tower crane and the parking position of the trailer and the tower crane could be in the same area, the sum of the values corresponding to all genes is "2".

$$P = P_c + P_t = 2$$

$$P_c = P_{c1} + P_{c2} + \cdots + P_{cm-1} + P_{cm} = 1$$

$$P_t = P_{t1} + P_{t2} + \cdots + P_{tn-1} + P_{tn} = 1$$

P : length of gene
P_c : Installable location of T/C
P_t : placeable location of Trailer

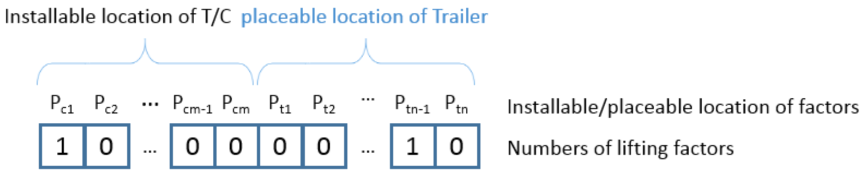

Figure 3-7. Definition of the Structure of Chromosomes

The gene defined in this way acts as a factor for deriving the optimum location of the tower crane and transport trailer depending on the installation location of the modular unit in the mid-to-high-rise modular construction. Repeatedly carry out the location where the lifting distance becomes the minimum while repeating the work of confirming the arrangement of the two lifting factors in various ways and the result of the execution and the capacity of the more optimal tower crane is calculated can be obtained. Therefore, this is expected to result in the construction cost benefit in the rental fee. Also, the more run it by repeating the work, the better you get the results, the better the results of the genetic algorithm program, the better you will get the better results the longer you run.

3.5. Output Derivation Process

This stage of actually going through all preparatory stages that have been advanced and actually driving the model and confirming the result. In the model, confirmed that the capacity of the tower crane that won by confirming the arrangement result of the lifting elements such as the tower crane did not have any problem in terms of lifting distance, lifting weight, and lifting height, compare the rental fee and derive the optimum tower crane to present the results that the operator can refer to. The configuration of the lifting equipment selection model used in this research is as follows.

step 0 : Define the input factors and variables used in the model and construct the database of the tower crane(Figure 3-8). At this stage, prepare for model driving by inputting the previously prepared input factor and database of the crane.

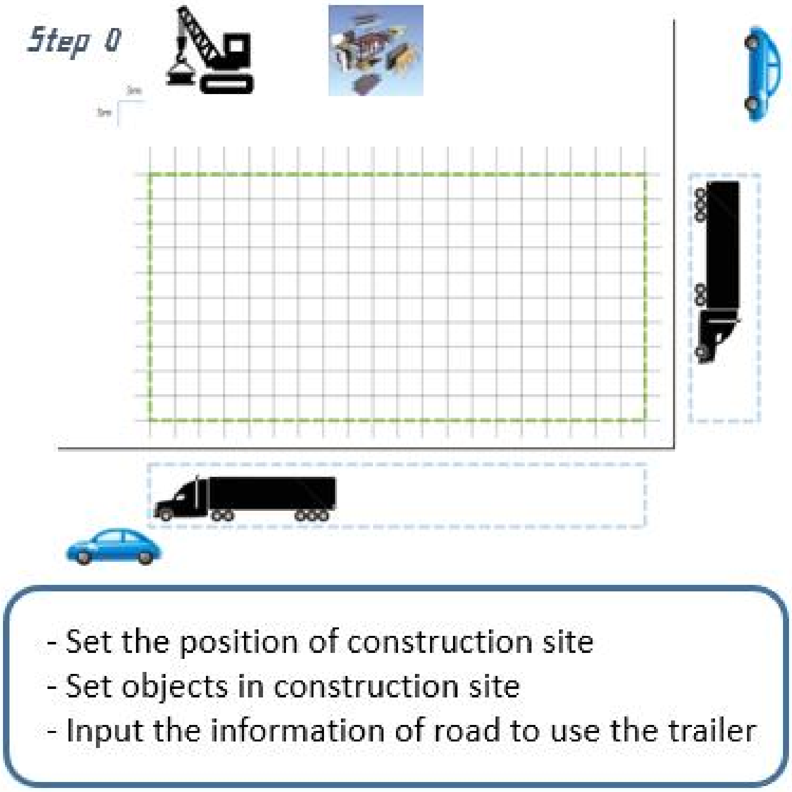

Figure 3-8. Step 0 of Model Process

step 1 : Determine the initial capacity of the tower crane and check the value of the optimal gene derived through the genetic algorithm process. At this time, the value of the gene is the position of the tower crane and the transportation trailer, the optimum combination is to find the smallest value of a combination's result among the maximum value among the distances between the tower crane and transport trailer, tower crane and the modular unit installation position(Figure 3-9).

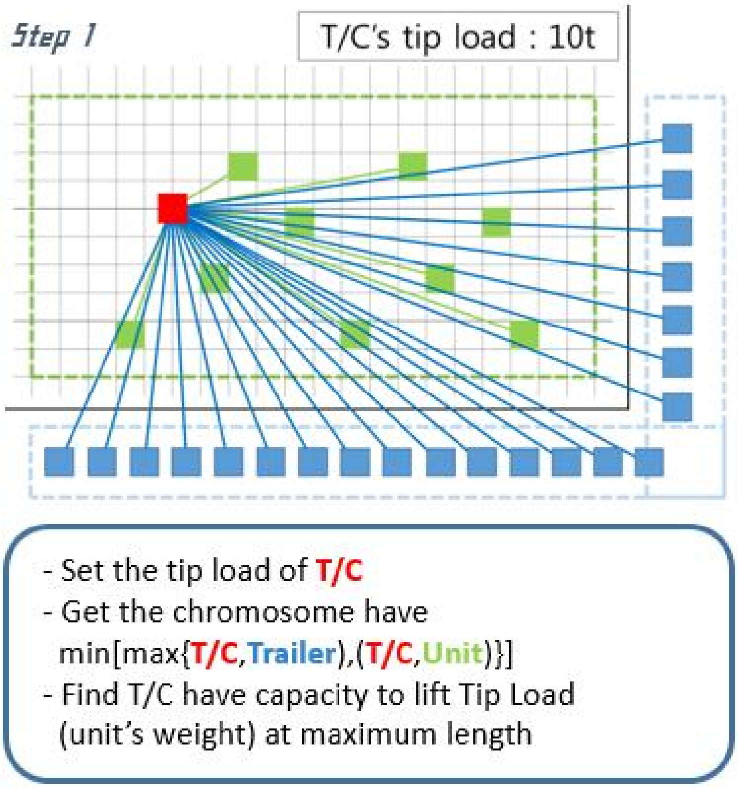

Figure 3-9. Step 1 of Model Process

step 2 : After comparing the tip load of the tower crane that can check in database of tower crane and the longest lifting length that came out at the first step, primary selection of combinations of lifting tower crane. After that compare the height of the mid-to-high-rise modular building with the self-reliance height of the tower crane and confirm the propriety of tower crane(Figure 3-10).

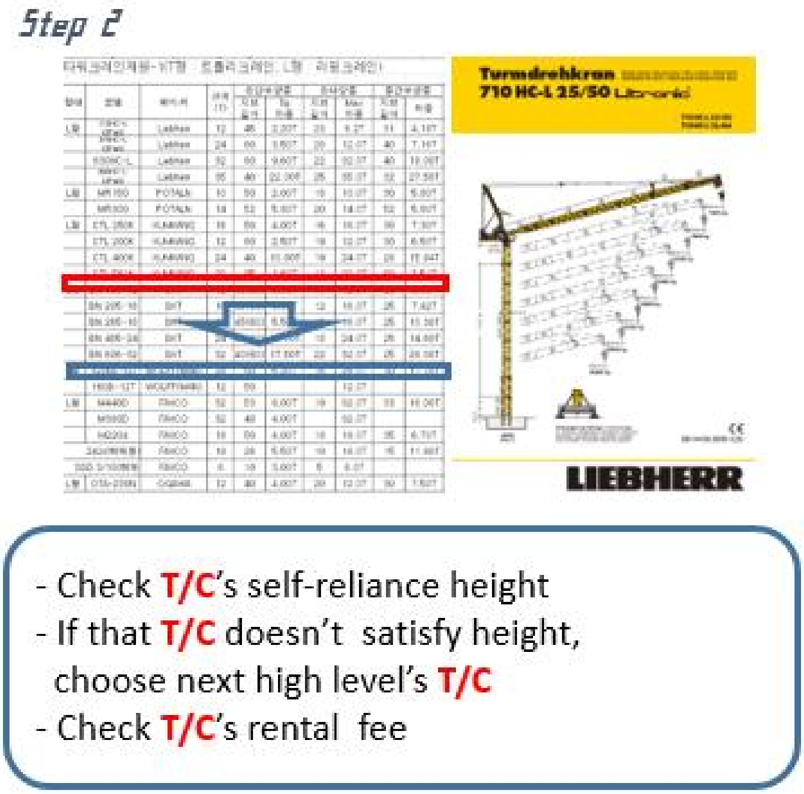

Figure 3-10. Step 2 of Model Process

step 3 : If the weight of the modular unit changed, return to the first step and reselect the tower crane

It is possible to select a tower crane that takes into consideration both the lifting capacity and the rental fee simultaneously by confirming the result value of the model which has come out through process, information of the tower crane that can be used in the decision making process between the designer and the constructor can be derived(figure 3-11).

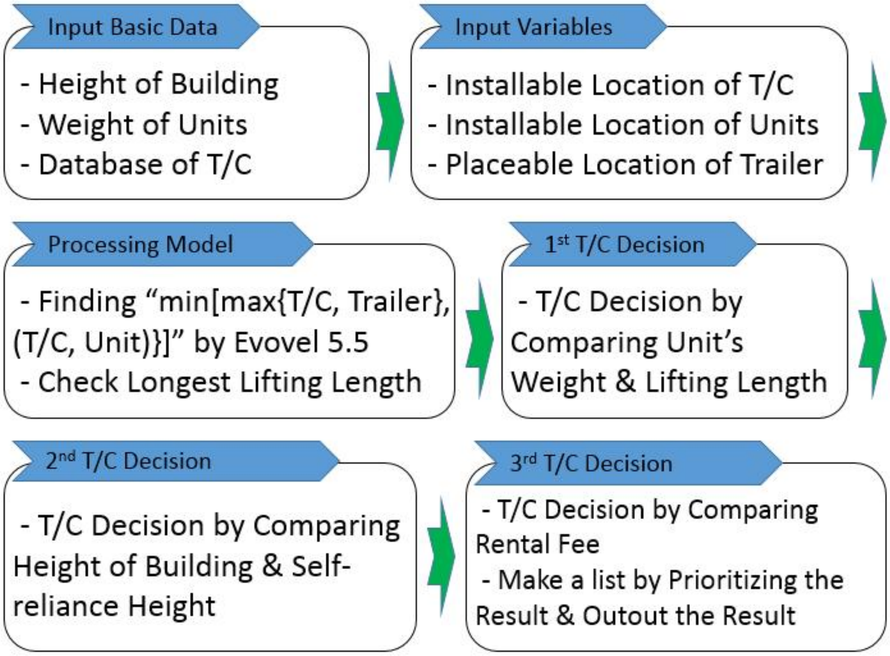

Figure 3-11. Conclusion Finding Process

3.6. Summary

In this chapter, described the process of the tower crane selection model of the mid-to-high-rise modular building project.

First, advance the chromosome definition of genes used in genetic algorithms, performed the modeling of the modular building site, confirmed the input factor and the output factor in model. The lifting equipment selection model consists of three steps, presented specific explanation of these steps.

Chapter 4. Case Study

In this Chapter, in order to confirm the validity of the tower crane selection model used for the mid-to-high-rise modular building project that proposed in this research, the case study was conducted assuming a future modular project. A modular project selected as a comparison target is a construction project that named Prefabricated apartment test site construction(assumed name)(Table 4-1). This plan is a project which is not yet actually progressed, it is a seven story modular building that formed by the modular units(by August, 2016). In this project, since the stacking height is not high(up to about 25 m), a mobile crane was chosen. However, in this study, perform comparative analysis assuming that it is a mid-to-high-rise building with the same construction site and use of single tower crane for comparison with the mid-to-high-rise building.

Table 4-1. Outline of Test Site Building Project

Classification	Contents
Name	Prefabricated apartment test site construction (assumed name)
Location	000, 00 dong, Gangnam-gu, Seoul
Site area	3,070.50㎡
Purpose	apartment, commercial facilities
Building area	1,384.90㎡
Total floor area	3,063.78㎡
Stories	1 basement story, 7 ground stories
Max height	27m
Structure	Precast concrete (1, 2story) + modular unit(3 ~ 7story, roof)
No. of units	62 units(private room : 40 units, common use : 22 units)

4.1. Existing Lifting Plan

Prefabricated apartment test site construction(assumed name) is 27m in height, 7 stories above the ground and 1,385m^2 in construction area, housing section is composed of a total of 28 households. The total number of modular units used in this project is 62, the modular unit assumes the use of 3m × 6m, 2m × 6m modules(Figure 4-1). In this project, plan that the modular unit transport trailer will be located on the road near the construction site and cannot be located in the construction site in a downtown that has a small spare site(Figure 4-2).

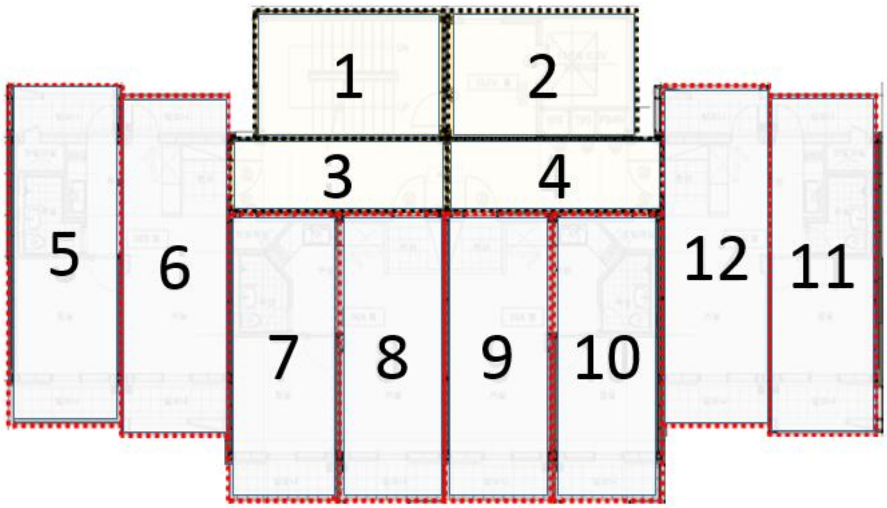

Figure 4-1. Ground Plan and Module Arrangement of Test Site

In order to convert this project into a mid-to-high-rise modular project, assumed that the plan of typical floor is similarly stacked on each floor. Therefore, in this research, set it to the mid-to-high-rise modular building with 15 floor, 45m height (height of floor is about 3m)

Also, on the construction plan, confirm that are placing a single tower crane and a single trailer. The plan of what sort of tower crane is to be used has not been confirmed, and it is assumed that the use of an arbitrary tower crane is used. So, for convenience the type of tower crane used for this research are the data of Liebherr and Potain company's tower crane that is most frequently used in Korea. The optimization algorithm program uses Evolver 5.5 and Microsoft Excel 2010, initial population size is 100, rate of mutation is set to 0.1. At this time, crossing applies uniform crossover calculation, and the crossover rate is set to 0.5. Based on the given data, the optimum lifting equipment selection is made through the tower crane location and capacity selection model.

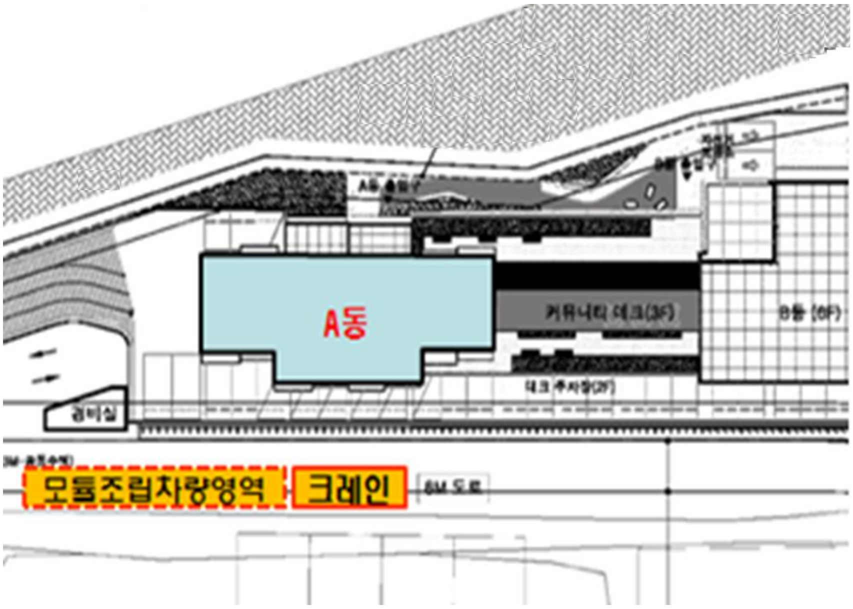

Figure 4-2. Arrangement of Lifting Equipment of Test Site

1) The coordinate of the modular unit's center of gravity is included in the planned installation location of the modular unit, the position of the tower crane and the trailer are set so that it can be installed in all locations, reflecting the coordinates of installable positions. At this time, The trailer for transporting the modular unit is capable of singular driving, and the number of tower cranes installed and operated is also planned to be singular.

2) Enter the lifting weight and the building height that the tower crane actually has to lift. The lifting weight is the heaviest weight used in the project, considering the efficiency of work. In this project, set to 14ton, considering 12ton which is the weight of the heaviest modular unit on this project and 2ton which is the weight of balance beam to be fastened to prevent

deformation of lifting modular unit at the same time.

3) When input of the initial data value is completed and the installation place of the crane and the placeable location of trailer are to be selected by using the genetic algorithm. Next, the distance between the tower crane installation position and the installation planned place of the modular unit is all calculated and the longest distance among the calculated distances is indicated in the represent value. In the same process, calculate the distance between the place where the trailer can be placed and the place where the tower crane is installed and the longest distance among the calculated distances is indicated in the represent value. Next, the above-calculated maximum value in binary is derived, since this distance is the minimum condition that the lifting equipment must lift.

4) When the longest lifting distance is confirmed based on the position of the tower crane and the position of the trailer, a tower crane combination that satisfies both the lifting distance and the weight from the DB of the tower crane entered in advance is derived.

5) A tower crane combination that has higher the self-reliance height than the height of the building among the derived tower crane combination is re-derived. Among them, a tower crane with the smallest tip load has the smallest rental fee of the tower crane. Therefore, when selecting this crane, can maximize benefits in terms of economic. In the case of this research project, confirmed the longest lifting distance is 15.4m(Figure 4-3, Table 4-2).

Table 4-2. Result Summary of Real Planning

Classification	Contents
No. of units	62 units(apartment : 40 units, common use : 22 units)
Weight of units	14ton(unit : 12ton, balance beam : 2ton)
Max. height	45m
Longest distance of crane-units	15.4m
Longest distance of crane-trailer	11.5m
Longest lifting distance	15.4m

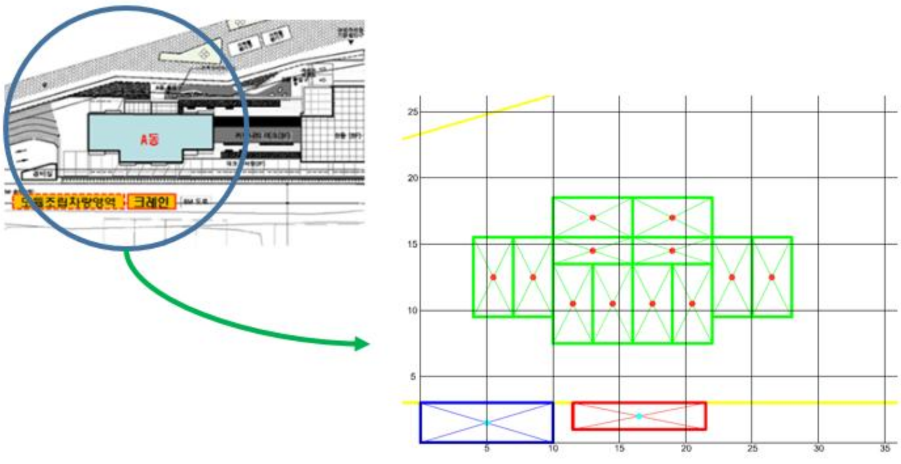

Figure 4-3. Conversion of Real Site for Modeling

4.2. Model Application

Arranged each element to confirm the capacity of the tower crane and the position of the transport trailer of Prefabricated apartment test site construction(assumed name). In the case of tower cranes, placed near the building to minimize lifting distance, modular unit transport trailer assumes the construction of the downtown, so it can only be placed on the carriage road. The installation position of the modular unit proceeds in the same way as the existing modular unit arrangement(Figure 4-4).

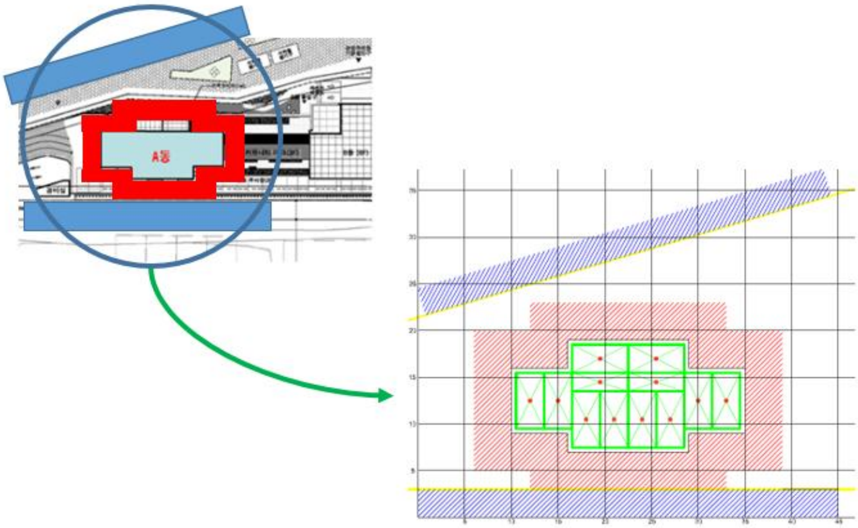

Figure 4-4. Conversion of Virtual Site for Modeling

The model was executed about 24 times, and the execution time was variously carried out up to 72 hours or more in 8 hours. Executive result of simulation under given conditions, derived the longest distance between the tower crane and the modular units is 12.9m, the longest distance between the tower crane and the transport trailer is 8.7 m. The final location of the tower crane and the transport trailer derived using the results of this model are the same as those shown in Figure 12, 1st, 2nd, and 3rd ranked tower cranes confirmed with the optimum tower crane were derived as the following results(Table 4-3). In this model, not only presenting one tower crane model that satisfies given conditions presenting up to the third, the person in charge make a final decision, will be able to refer to this result when deciding the selection of the tower crane.

Table 4-3. Result Summary of Modeling

Classification	Contents			
No. of units	62 units(apartment : 40 units, common use : 22 units)			
Weight of units	14ton(unit : 12ton, balance beam : 2ton)			
Max. height	45m			
Longest distance of crane-units	12.9m			
Longest distance of crane-trailer	8.7.m			
Longest lifting distance	12.9m			
Optimum tower crane	1st	Potain MR295H16	59m	1.6mil₩/month
	2nd	Liebherr 180HC-L 8/16	65m	1.6mil₩/month
	3rd	Potain MR295H20	59m	2.0mil₩/month

4.3. Result Analysis

In order to confirm the effectiveness of the development of the model implemented in this research, compared it with the original construction plan. Derived through this research of case studies, the location of the tower crane, the location of transport trailer and the capacity of the tower crane of the mid-to-high-rise modular construction are as follows(Table 4-4).

Table 4-4. Result Comparison

Classification	Contents		
	Existing	After Modeling	Variation
Max. height	45m		
Weight of units	14ton		
Location of T/C	16.5, 2.0	22.5, 5.0	
Location of Trailer	5.0, 1.5	14.5, 1.5	
Longest distance of crane-units	15.4m	12.9m	-2.5m
Longest distance of crane-trailer	11.5m	8.7m	-2.8m
Longest lifting distance	15.4m	12.9m	-2.5m
Optimum T/C		Potain MR295H16	
Rental fee of T/C		1.6mil ₩/month	

As a result of the research, the longest lifting distance between the tower crane and the modular unit through genetic algorithm decreased by 2.5m(existing : 15.4m, after modeling : 12.9m), the longest lifting distance between the tower crane and the transport trailer is also decreased by 2.8m(existing : 11.5m, after modeling : 8.7m). The longest lifting distance was the distance between the tower crane and the transport trailer, 12.9m(reduced by 2.5m). As a result Potain's MR295H16 has been derived from the optimal tower crane that can lift the weight of 14ton to a height of 45m, The optimum position of the tower crane and the transport trailer is also derived together(Figure 4-5).

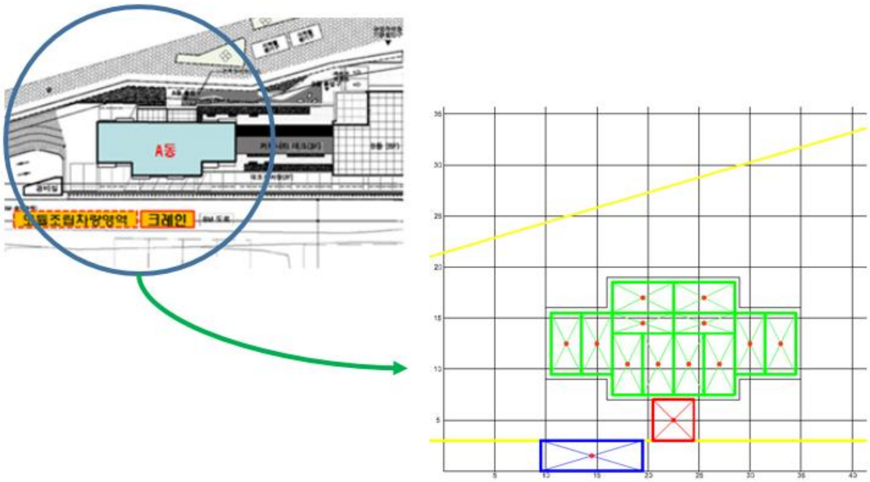

Figure 4-5. Optimal Arrangement of Lifting Equipments After Process

Selected as a case of this research Construction of a Prefabricated apartment test site construction(assumed name), R&D(research and development) and promotion of business are carried out, it may happen that the weight of the modular unit is changed while the design progress in some cases. In this case, change the weight of the initialized modular unit, by redoing the model get the new result, it is possible to provide information related to the lifting work to both the designer and the constructor. In this project, the placement plan of the building's modular units is not complicated, so the difference in result by the existing tower crane selection method was not so large, as the building size of the modular construction increases. However, the operation with a tower crane of the high capacity is necessary, the higher the specification is directly proportional increasing the rental fee, the value of the obtained information get through this model is judged to be more useful.

4.4. Summary

In this chapter, in order to confirm the appropriacy of the tower crane selection model used in the mid-to-high-rise modular building project proposed in this research, we applied it assuming a future modular project. Application result of lifting equipment selection model, confirm that the longest lifting distance of the tower crane decreases, based on the derived data, can confirm the recommended model of the appropriate tower crane and the rental fee. The results of the model can be used as useful information related to the selection of tower cranes by designers and constructors who are members of projects for future modular projects.

Chapter 5. Conclusion

In this chapter, present the summary of the development process of tower crane's capacity and location selection of mid-to-high-rise modular project, and the contribution and limitation of this research.

5.1. Result and Discussion

The modular construction is a method of coexistence between the manufacturing work at the factory and the installation work at the site in harmony. Lifting work on site work is important as it takes an important role in the installation work of the modular unit and it has a high importance in that it affects the entire project in the future. As a result, the selection and operation of the lifting equipment that is indispensable for lifting work can be regarded as an important element of the work at the site, have an influence on construction time and cost in construction progress.

However, existing lifting equipment selection and placement are carried out based on the experience and intuition of workers based on the criteria such as checking the capacity of lifting equipment, the working radius through inter-work interference, factors for increasing construction costs.

Therefore, in this research, it is necessary to confirm the variables related to the lifting work in order to carry out on-site work indispensable for the progress of the mid-to-high-rise modular projects, especially lifting work, constructed a model of genetic algorithm using this variable and confirmed the capacity of the tower crane and the optimum position of the tower crane and the transport trailer.

The variables considered in this model are the tower crane used for lifting work, the modular unit will be installed, and the transport trailer that moves the modular unit. And selected the capacity of the tower crane with the smallest rental fee and selected the location of the tower crane and transport trailer, while confirming the relation between the elements that satisfy the given lift condition. Conducted verifications on modular projects to be conducted in the future for checking the reliability of the research.

5.2. Contribution

As a result, it can be used as a tower crane selection tool that applies logical and objective criteria to both the designer and the constructor in the future. In particular, that can give a lot of help to select the location and capacity of the required tower crane for the mid-to-high-rise modular construction. In addition, the results derived through the execution of the model are related to checking for rough layout and capacity selection of the lifting equipment and can be used as a tool for communication concerning construction worker and builder construction at the initial stage of design of the mid-to-high-rise modular projects.

In this way, on an academic side, it is possible to find a contribution point in that it promoted the placement of a tower crane in accordance with objective and logical standards, not depending on experience and intuition. In addition, can find a contribution point in terms of a model considering various lifting factors of modular construction with differences from general constructions dealt with in conventional lift related research. On an economic side, it is possible to measure the rental fee of a tower crane of an appropriate cost for the owner and use it as a basic material for judging the validity of the design. Particularly in the case of a system in which designers and constructors can intersect with design and construction plans like the DB ordering method, there is an positive effect of communication between them and this also facilitates the smooth progress of the project. So it is expected to be useful in the mid-to-high-rise modular construction.

5.3. Further Study

The limitations of this research can be roughly divided into two.

The first point is related to the number of the tower cranes used at the mid-to-high-rise modular construction site. In this research only proceeded with the use of a single tower crane, for this reason, difficult to apply to cases using multiple tower cranes, and additional research will be required.

The second limitation is that did not reflect the changing situation of the site as it progressed to construction. Depending on the change in time, various changes occur in the site, which can also be applied to transportation trailers as well. However, in this study, considered that there is no consideration for transportation trailer movement accompanying the change of time, and future research will be necessary.

The last limitation is that it did not take into consideration the lifting order that must be lifted with the tower crane and the installation position to strengthen the structure of the tower crane.

It is confirmed whether the location of the selected tower crane influences the efficiency of the lifting order, needed to reflect additional criteria, such as increasing the priority for strengthening and confirming the location selection, at sites where lateral force resistance needs to be enhanced.

Bibliography

Chae, Hee Dong. (2002). Development of Tower Crane Planning Process in High-rise Building Projects, master’s thesis, Seoul National University.

Cho, Ji-Hun., and Cho, Heung-Goo. (2009). An Analysis of Optimized Super Tall Building Tower Crane Selection Which Related with Project Construction Period. JOURNAL OF THE KOREA INSTITUTE OF BUILDING CONSTRUCTION, 9(6), 131-139.

Chun, Jae-Youl., and Oh, Seung-Jun. (2003). Constitutional Directions of Decision Support Process for Cooperative Design in Architectural Design Phase. JOURNAL OF THE ARCHITECTURAL INSTITUTE OF KOREA Structure & Construction, 19(11), 173-180.

Chun, Jae-Youl. (2005) The Process Model for Project Management of Design-Build System and Constitution of Database. Proceeding of annual conference of the Korea Institute of Construction Engineering and Management, 109-117.

Gwak, Han-Seong., Yi, Chang-Yong., and Lee, Dong-Eun. (2014). Methodology for Selecting Optimal Earthmoving Haul-Routes using Genetic Algorithm. JOURNAL OF THE ARCHITECTURAL INSTITUTE OF KOREA Structure & Construction, 30(3), 141-150.

Han, Soon-Mi., Baek, Seung-Woo., Jo, Seon-Yeong., Lee, Dae-Woo., and Kim, Hae-Dong. (2008). Optimization of the Satellite Mission Scheduling Using Genetic Algorithms. Journal of The Korean Society for Aeronautical and Space Sciences, 36(12), 1163-1170.

Ho, Jong-Kwan., Kim, Sun-Kuk., and Kook, Dong-Hoon. (2007). A System for the Selection of the Optimum Tower Cranes (Opt-TC). Korean Journal of Construction Engineering and Management, 8(6), 216-226.

Hong, Sung-Gul. (2014). Structural Design Guidelines for Middle to High-rise Modular Buildings for Architects and Engineers. Review of Architecture and Building Science, 58(5), 15-19.

Jeong, Young-Sun., Kim, Kyoung-Woo., and Lim, Seok-Ho. (2015). Evaluation of the Environmental Performance of the Prefabricated Modular Housing using Mock-up Models. Journal of Korean Institute of Architectural Sustainable Environment and Building Systems, 9(2), 128-133.

Joo, Jin Ho., Lee, Deok Chan., and Shin, Hyun Shik. (1994). A Study on the Crane Location Optimization in the High-rise building Construction. JOURNAL OF THE ARCHITECTURAL INSTITUTE OF KOREA Structure & Construction, 14(1), 491-981.

Kim, Dong-Jin., Song, Young-Suk., and Lim, Hyoung-Chul. (2002). Rationalization the Lift car Planning Method in a High-rise Building Project. Proceeding of annual conference of the architectural institute of Korean, 22(2), 483-486.

Kim, Jung-Jin. (2003). A Study on the Hoisting Planning System in Highrise Building Construction, Doctoral dissertation, Myungji University.

Kim, Kyong Ju., Kim, Kyoungmin., and Lee, Sang-kyu. (2009). Optimization of Multiple Tower Cranes and Material Stockyards Layout. Korea Journal of Construction Engineering and Management, 10(6), 127-134.

Kim, Minjung., Park, Moonseo., Lee, Hyunsoo., Lee, Jeonghoon., and Hyun, Hosang. (2014). The Activation Plan of Modular Construction in Educational Facilities using QFD. Korea Journal of Construction Engineering and Management Conference Proceeding 11, 113-114.

Kim, Minjung., Park, Moonseo., Lee, Hyunsoo., Lee, Jeonghoon., and Lee Kwangpyo. (2015). Development of Manufacturing Planning for Multi Modular Construction Project based on Genetic-Algorithm. Korea Journal of Construction Engineering and Management, 16(5), 54-64

Lee, Hyun Soo., Chae, Hee Dong., and Jang, Myung Houn. (2002). Development of Tower Crane Planning Process in High-rise Building Projects. JOURNAL OF THE ARCHITECTURAL INSTITUTE OF KOREA Structure & Construction, 18(6), 119-126.

Lee, Hyun-soo., Ji, Sae-hyun., Park, Moon-seo., and Song, Sang-hun. (2007). Analyzing Characteristics of Design-Build Delivery System in Korea Using System Dynamics Modeling. Journal of Korean Institute Of Construction Engineering and Management, 8(5), 119-131

Lee, Myung-Do., Won, Myeong-Kyun., Lee, Ung-Kyun., Cho, Hun-Hee., and Kang, Kyung-In. (2014). Integrated Lifting Model of Planning and Operation for Finishing Works in Tall Building Construction. JOURNAL OF THE ARCHITECTURAL INSTITUTE OF KOREA Structure & Construction, 30(5), 125-133.

Lee, Sangwook. (2011). Efficient Genetic Algorithm for Resource Constrained Project Scheduling Problem. JOURNAL OF THE KOREA CONTENTS ASSOCIATION, 11(6), 59-66.

Lee, Ung-Kyun., Kim, Jae-Youp., Seo, Deok-Seok., and Kang, Kyung-In. (2004). Genetic Algorithms of Planning Transportation - Focused on Tower Crane -. JOURNAL OF THE ARCHITECTURAL INSTITUTE OF KOREA Structure & Construction, 20(2), 127-134.

Lee, yol. (1993). A Study on the Towercrane Location with Efficient planing of lifting, Master of Science Engineering, Hanyang University

Leung, A. W., and Tam, C. M. (1999). Models for assessing hoisting times of tower cranes. Journal of construction engineering and management, 125(6), 385-391.

Oh, Kyoungsu. (2004). A study on the Efficient cooperative design method of specialty-fields for building project, master's thesis, Chung-Ang University.

Park, Moonseo., Yang, Youngjun., Lee, Hyun-soo., Han, Sang-won., and Ji, Sae-hyun. (2011). Korea Journal of Construction Engineering and Management. Korea Journal of Construction Engineering and Management, 12(1), 43-52.

Rodriguez-Ramos, W. E., and Francis, R. L. (1983). Single crane location optimization. Journal of Construction Engineering and Management, 109(4), 387-397.

Shin, Hyun-Kyu., and Ahn, Yong-Han. (2015). A Development of The Module Lifting Process for Modular Construction. Proceeding of annual conference of the architectural institute of Korean, 209-210.

Tam, C. M., Tong, T. K., and Chan, W. K. (2001). Genetic algorithm for optimizing supply locations around tower crane. Journal of construction engineering and management, 127(4), 315-321.

Zhang, P., Harris, F. C., Olomolaiye, P. O., and Holt, G. D. (1999). Location optimization for a group of tower cranes. Journal of construction engineering and management, 125(2), 115-122.

Homepage of Jade Cheng. (2016.9.1.). (http://jade-cheng.com/au/coalhmm/optimization/)

Homepage of Tufts University School of Engineering. (2016.9.1). (http://www.cs.tufts.edu/comp/131/classpages/)

Appendix

A. Explanation of Input and Output Variables in Model

A.1. Tower Crane DB

1	2	3	4						5	6
형태	메이커	모델명					Tip Load		자립고	양중비용 (만원)
			jib 길이	양중 하중	jib 길이	양중 하중	jib 길이	양중 하중		
L형	Liebherr	280 HC-L 8/16(24 HC 630)	20.0	16.0	25.0	12.3	65.0	0.0	64.9	1,601.0
L형	Liebherr	280 HC-L 12/24(24 HC 630)	20.0	23.0	25.0	18.0	65.0	0.0	59.1	2,403.0
L형	Liebherr	280 HC-L 16/28(24 HC 630)	20.0	22.5	25.0	17.5	65.0	0.0	59.1	2,800.0
L형	Liebherr	357 HC-L 12/24(24 HC 630)	20.0	24.0	25.0	22.8	65.0	0.0	53.3	2,402.0
L형	Liebherr	357 HC-L 18/32(24 HC 630)	20.0	27.5	25.0	21.0	65.0	0.0	53.3	3,202.0
L형	Liebherr	542 HC-L 12/24(24 HC 630)	20.0	30.0	25.0	24.0	65.0	4.8	47.5	2,400.0
L형	Liebherr	542 HC-L 18/36(24 HC 630)	20.0	36.0	25.0	29.7	65.0	4.3	47.5	3,600.0
L형	Liebherr	710 HC-L 25/50(24 HC)	20.0	50.0	25.0	40.3	65.0	7.6	52.0	5,000.0
L형	Liebherr	710 HC-L 32/64(24 HC)	20.0	50.8	25.0	38.3	65.0	7.2	52.0	5,125.0
L형	Potain	MR90C	20.0	7.0	25.0	5.1	65.0	0.0	54.5	800.0
L형	Potain	MR160C	20.0	10.0	25.0	8.5	65.0	0.0	54.2	1,000.0
L형	Potain	MR225A	20.0	13.0	25.0	9.7	65.0	0.0	52.5	1,400.0
L형	Potain	MR295H16	20.0	16.0	25.0	14.6	65.0	0.0	58.7	1,600.0
L형	Potain	MR295H20	20.0	19.2	25.0	14.3	65.0	0.0	58.7	2,000.0
L형	Potain	MR418	20.0	24.0	25.0	19.0	65.0	0.0	74.0	2,401.0
L형	Potain	MR608	20.0	32.0	25.0	28.8	65.0	0.0	77.8	3,200.0
L형	Potain	MR618	20.0	32.0	25.0	27.6	65.0	0.0	74.4	3,201.0

1. Type of Tower Crane : T-type or L-type

2. Tower Crane making company

3. Name of model

4. Tip load of Tower Crane : When length of jib is 20m, 25m, 30m, 35m, 40m, 45m, 50m, 55m, 60m, 65m

5. Self-reliance height

6. Rental fee of Tower Crane : million won / month

A.2. Input Values

1

유닛	x	y	거리
	12.0	12.5	4.5
	15.0	12.5	7.3
	18.0	10.5	10.0
	21.0	10.5	13.0
	24.0	10.5	16.0
	27.0	10.5	19.0
	19.5	14.5	12.2
	19.5	17.0	13.2
	25.5	14.5	18.0
	25.5	17.0	18.7
	30.0	12.5	22.1
	33.0	12.5	25.1

2

크레인	x	y
0	8.0	7.0
0	8.5	7.0
0	9.0	7.0
0	9.5	7.0
0	10.0	7.0
0	10.5	7.0
0	11.0	7.0
0	11.5	7.0
0	12.0	7.0
0	12.5	7.0
0	13.0	7.0
0	13.5	7.0
0	14.0	7.0
0	14.0	6.5
0	14.0	6.0
0	14.0	5.5
0	14.0	5.0
0	14.5	5.0
0	15.0	5.0
0	15.5	5.0
0	16.0	5.0
0	16.5	5.0
0	17.0	5.0

3

트레일러	x	y
0	0.0	1.5
0	0.5	1.5
0	1.0	1.5
0	1.5	1.5
0	2.0	1.5
0	2.5	1.5
0	3.0	1.5
0	3.5	1.5
0	4.0	1.5
0	4.5	1.5
0	5.0	1.5
0	5.5	1.5
0	6.0	1.5
0	6.5	1.5
0	7.0	1.5
0	7.5	1.5
0	8.0	1.5
0	8.5	1.5
0	9.0	1.5
0	9.5	1.5
0	10.0	1.5
0	10.5	1.5
0	11.0	1.5

4

크레인 최종	x	y
설치	8.0	10.5

트레일러 최종	x	y
주차	18	28.5

5

건물 높이(m)
50.0

유닛 무게(ton)
14.0

1. Modular Units location that can be installed : Can be input and change by users

2. Tower Crane location that can be installed

- Tower Crane installation location's coordinate : Can be input and change by users

- Number of Tower Crane installation on location : Evolver program will change numbers using result of Genetic Algorithm processing

3. Trailer location that can be placed

- Trailer placed location's coordinate : Can be input and change by users

- Number of Trailer placed on location : Evolver program will change numbers using result of Genetic Algorithm processing

4. Result of input values : Location of Tower Crane and trailer

5. Height of building and weight of the modular unit : Can be input and change by users

A.3. Judgment Process

1	2	3		4		5		6		
모델명	자립고	거리검증	거리가능	무게검증	양중가능	높이검증	높이가능	임대료	랭크	우선순위
Liebherr 180 HC-L 8/16(24 HC 630)	64.9	9.8	가능	불가능	불가능	불가능	불가능	0	#N/A	NO
Liebherr 280 HC-L 12/24(24 HC 630)	59.1	13.5	가능	불가능	불가능	불가능	불가능	0	#N/A	NO
Liebherr 280 HC-L 16/28(24 HC 630)	59.1	13.8	가능	불가능	불가능	불가능	불가능	0	#N/A	NO
Liebherr 357 HC-L 12/24(24 HC 630)	53.3	18.1	가능	18.1	가능	18.1	가능	2,402	2	better
Liebherr 357 HC-L 18/32(24 HC 630)	53.3	18.0	가능	18.0	가능	18.0	가능	3,202	5	bad
Liebherr 542 HC-L 12/24(24 HC 630)	47.5	24.0	가능	24.0	가능	불가능	불가능	0	#N/A	NO
Liebherr 542 HC-L 18/36(24 HC 630)	47.5	24.2	가능	24.2	가능	불가능	불가능	0	#N/A	NO
Liebherr 710 HC-L 25/50(24 HC)	52.0	31.2	가능	31.2	가능	31.2	가능	5,000	6	bad
Liebherr 710 HC-L 32/64(24 HC)	52.0	32.0	가능	32.0	가능	32.0	가능	5,125	7	bad
Potain MR90C	54.5	3.9	가능	불가능	불가능	불가능	불가능	0	#N/A	NO
Potain MR160C	54.2	6.5	가능	불가능	불가능	불가능	불가능	0	#N/A	NO
Potain MR225A	52.5	7.4	가능	불가능	불가능	불가능	불가능	0	#N/A	NO
Potain MR295H16	58.7	11.6	가능	불가능	불가능	불가능	불가능	0	#N/A	NO
Potain MR295H20	58.7	11.1	가능	불가능	불가능	불가능	불가능	0	#N/A	NO
Potain MR418	74.0	15.6	가능	15.6	가능	15.6	가능	2,401	1	best
Potain MR608	77.8	23.8	가능	23.8	가능	23.8	가능	3,200	3	good
Potain MR618	74.4	23.0	가능	23.0	가능	23.0	가능	3,201	4	bad

1. Name of model

2. Self-reliance height

3. Verification by maximum lifting length and judgment

4. Verification by lifting weight and judgment

5. Verification by lifting height and judgment

6. Checking rental fee and set prioritizes

B. Result of Simulation by Developed Model

B.1. Arrangement of Developed Model's Result

Date	Time	Longest Lifting Length(m)	Tower Crane			
			Rank	Model	Self Reliance Height(m)	Rental Fee (million ₩ /month)
160728 ~ 160729	16:39	15.44	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160801 ~ 160802	19:17	15.44	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160803 ~ 160804	15:33	15.44	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160804 ~ 160805	16:07	15.44	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160805 ~ 160808	64:23	12.90	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20

160808 ~ 160809	17:42	12.90	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160809 ~ 160810	17:19	13.51	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160810 ~ 160812	39:06	13.51	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160812 ~ 160816	93:02	12.90	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160816 ~ 160817	16:01	13.51	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160817 ~ 160822	112:35	12.90	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160822 ~ 160823	16:59	13.51	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20

160823	**19:55**	**13:51**	**1st**	**Potain MR295H16**	**59**	**16**
~			**2nd**	**Leibherr 180 HC-L 8/16**	**65**	**16**
160824			**3rd**	**Potain MR295H20**	**59**	**20**
160824	**18:51**	**13.51**	**1st**	**Potain MR295H16**	**59**	**16**
~			**2nd**	**Leibherr 180 HC-L 8/16**	**65**	**16**
160825			**3rd**	**Potain MR295H20**	**59**	**20**
160825	**17:02**	**13.51**	**1st**	**Potain MR295H16**	**59**	**16**
~			**2nd**	**Leibherr 180 HC-L 8/16**	**65**	**16**
160826			**3rd**	**Potain MR295H20**	**59**	**20**
160826	**63:38**	**12.90**	**1st**	**Potain MR295H16**	**59**	**16**
~			**2nd**	**Leibherr 180 HC-L 8/16**	**65**	**16**
160829			**3rd**	**Potain MR295H20**	**59**	**20**
160829	**17:04**	**13.51**	**1st**	**Potain MR295H16**	**59**	**16**
~			**2nd**	**Leibherr 180 HC-L 8/16**	**65**	**16**
160830			**3rd**	**Potain MR295H20**	**59**	**20**
160830	**16:17**	**13.51**	**1st**	**Potain MR295H16**	**59**	**16**
~			**2nd**	**Leibherr 180 HC-L 8/16**	**65**	**16**
160831			**3rd**	**Potain MR295H20**	**59**	**20**
160831	**16:50**	**13.51**	**1st**	**Potain MR295H16**	**59**	**16**
~			**2nd**	**Leibherr 180 HC-L 8/16**	**65**	**16**
160901			**3rd**	**Potain MR295H20**	**59**	**20**

160901 ~ 160902	16:42	13.51	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160902 ~ 160905	64:15	13.51	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160907 ~ 160908	17:26	12.90	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160908 ~ 160909	16:07	13.51	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20
160909 ~ 160912	64:21	12.90	1st	Potain MR295H16	59	16
			2nd	Leibherr 180 HC-L 8/16	65	16
			3rd	Potain MR295H20	59	20

국 문 초 록

모듈러 프로젝트는 공장에서의 제작 작업과 현장에서의 설치 작업이 조화를 이루면서 진행되는 공법이다. 특히 현장에서의 설치 작업 중에서 모듈러 유닛의 설치에 필수적인 작업 중에 하나인 양중 작업은 현장 작업에서 큰 비중을 차지한다. 따라서 프로젝트 초기단계에서의 정확한 양중작업 예측은 최적의 공사비용과 공사기간의 산정을 가능하게 한다.

하지만 기존의 양중 장비 선정은 시공자의 경험과 직관에 의거하여 진행되는 경우가 많아 객관적이고 논리적인 기준이 필요하다. 따라서 본 연구에서는 양중작업에 영향을 미치는 세 변수(타워크레인, 설치할 모듈러 유닛, 운송 트레일러)간의 관계를 통하여 최적의 타워크레인의 선정이 가능한 모델을 제안하였다. 이를 위해 본 연구의 방법론으로는 다수의 변수의 조합을 찾아내는데 효과적인 유전자 알고리즘을 사용하였으며, 중고층 모듈러 건축 현장을 좌표화하여 연구를 진행하였다. 이 연구의 타당성을 검증하기 위해 앞으로 진행될 모듈러 프로젝트에 대하여 검증을 실시하였다.

유전자 알고리즘을 통하여 최소의 양중 거리를 가지며 요구하는 양중 높이를 만족하는 타워크레인의 제원과 양중 관련 요소인 타워크레인과 모듈러 유닛 운송용 트레일러의 위치를 확인할 수 있었다. 향후 본 연구가 모듈러 건축 프로젝트에 사용될 경우 프로젝트 초기 과정에서 설계자와 시공자간의 공유 정보로 사용되어 최적의 양중계획 수립에 도움이 될 수 있다.

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