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A DEVELOPMENT OF A SUPPORTING SYSTEM FOR CONSTRUCTION SITE LAYOUT PLANNING

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การวางผังสถานที่ก่อสร้างสำหรับงานก่อสร้างอาคารเป็นกระบวนการทำงานที่สำคัญซึ่งต้องการความรู้และประสบการณ์ในหลายๆแขนง ผู้วางผังต้องศึกษาปัจจัยจำนวนมากเพื่อให้ได้มาซึ่งการวางผังสถานที่ก่อสร้างที่ดี มิฉะนั้นปัญหาที่ส่งผลกระทบต่อผลิตภาพของโครงการอาจเกิดขึ้นและนำไปสู่ความสิ้นเปลืองและความล่าช้า การศึกษานี้ตรวจสอบถึงปัจจัยที่ส่งผลต่อการวางผังสถานที่ก่อสร้าง และนำเสนอระบบเพื่อจัดทำการวางผังสถานที่ก่อสร้างในขั้นแรกของการก่อสร้าง การเก็บข้อมูลแบ่งออกเป็นสองส่วน ส่วนที่หนึ่งเป็นการสัมภาษณ์เบื้องต้นกับกลุ่มของผู้เชี่ยวชาญในด้านการวางผังสถานที่ก่อสร้างเพื่อให้ทราบถึงหลักการทำงานซึ่งสะท้อนต่อการทำงานจริง ส่วนที่สองเป็นการสัมภาษณ์โดยการประยุกต์ใช้พหุกรณีศึกษาเข้ากับกรณีศึกษาจำนวนห้ากรณี ผู้เชี่ยวชาญถูกร้องขอให้จัดการวางผังสถานที่ก่อสร้างให้กับกรณีศึกษาเหล่านี้โดยใช้ความรู้ของผู้เชี่ยวชาญ แบบฟอร์มการวิเคราะห์ข้อมูลเชิงคุณภาพที่มีชื่อว่า Tabular Method ได้ถูกประยุกต์ใช้เพื่อค้นหาความเหมือนหรือแตกต่างระหว่างกรณีศึกษาเพื่อระบุถึงปัจจัยที่ส่งผลต่อการวางผังสถานที่ก่อสร้างและสร้างฐานกฎเกณฑ์ความรู้ขึ้น ฐานกฎเกณฑ์เหล่านี้ถูกส่งกลับไปสู่กลุ่มผู้เชี่ยวชาญอีกครั้งเพื่อตรวจสอบถึงความถูกต้องในการแปลผล เพื่อให้ได้มาซึ่งความเป็นถูกต้องและเชื่อถือได้ของข้อมูล ปัจจัยที่ส่งผลกระทบต่อการวางผังสถานที่ก่อสร้างถูกแบ่งออกเป็นสิบสามกลุ่ม ได้แก่ การออกแบบของอาคาร ข้อจำกัดขององค์ประกอบในสถานที่ก่อสร้าง ความสัมพันธ์ขององค์ประกอบในสถานที่ก่อสร้าง สถานที่ตั้งสถานที่ก่อสร้าง การจราจรภายในสถานที่ก่อสร้าง กระบวนการทำงาน ข้อจำกัดของสถานที่ก่อสร้าง ข้อกำหนดและกฎหมาย พื้นที่ว่างในสถานที่ก่อสร้าง จำนวนบุคคลากร การมีอยู่ขององค์ประกอบในสถานที่ก่อสร้าง ระยะเวลาของโครงการ และชนิดของอาคาร แนวทางของการวางผังสถานที่ก่อสร้างได้ถูกจัดทำขึ้นจากปัจจัยเหล่านี้ และถูกนำมาใช้เป็นหลักของระบบสนับสนุนซึ่งใช้องค์ความรู้เป็นฐานและถูกพัฒนาโดยใช้รูปแบบ IF-THEN-ELSE การตรวจสอบผลได้ถูกจัดทำขึ้นกับการทำงานจริง โดยเปรียบเทียบฐานกฎเกณฑ์กับกรณีศึกษาอีกหนึ่งกรณีและเปรียบเทียบระหว่างผังสถานที่ก่อสร้างของผู้เชี่ยวชาญและของวิศวกรที่มีความเชี่ยวชาญน้อยแต่ได้รับความช่วยเหลือจากระบบ ผลการตรวจสอบพบว่าฐานกฎเกณฑ์ต่างๆมีความเหมาะสมและระบบสามารถสนับสนุนวิศวกรที่มีความเชี่ยวชาญน้อยให้สามารถทำการวางผังสถานที่ก่อสร้างได้

ภาควิชา วิศวกรรมโยธา ลายมือชื่อนิสิต ....

สาขาวิชา วิศวกรรมโยธา ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

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NATTHAPOL SAOVANA: A DEVELOPMENT OF A SUPPORTING SYSTEM FOR CONSTRUCTION SITE LAYOUT PLANNING. ADVISOR: ASSOC. PROF. TANIT TONGTHONG, Ph.D., 249 pp.

Construction Site Layout Planning (CSLP) for building construction is a crucial process that requires variety of knowledge and experience. A planner has to study numerous aspects in order to gain an effective CSLP. Otherwise problems that affect the productivity of a project could occur and lead to cost and schedule overruns. This study investigated the factors affecting CSLP and proposed a system for implementing CSLP in the first stage of a construction project. The data collection was divided into two parts. First, an exploratory interview with a group of experts in CSLP was conducted to acquire the principles of works as reflected in real practice. Second, a multiple case study was applied to five different cases where the experts were asked to manage CSLP from their knowledge. Tabular method was applied to find similarities and differences between cases in order to verify factors affecting the CSLP and to create knowledge rule bases. These rule bases were sent back to experts to validate whether the interpretation was correct to gain the generalizations, validity, and reliability of the results. The outputs of this research are the factors influencing CSLP and a proposed system in assisting CSLP. The factors affecting CSLP are divided into thirteen groups which are the design of the building, constraints of components, relationships between components, location of the site, traffic on the site, method of work, site constraints, specifications and regulations, free space, man power, availabilities of components, duration of the project, and type of the building. A guideline was developed based on these factors and was used as the core of the proposed system. The system acts as a supporting system developed in IF-THEN-ELSE basis. The validation of the results was conducted with the rule bases and the proposed system. The rule bases were assessed in one of the case studies, and the proposed system was justified based on the comparison of layouts between experts and low expertise engineers. It was found that rule bases were suitable while the system can assist low expertise engineers to be able to do CSLP.

Department:	Civil Engineering	Student's Signature	....
Field of Study:	Civil Engineering	Advisor's Signature	....
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Chapter 1
Introduction

1.1 Background

1.1.1 Construction site layout planning

Construction site layout planning (CSLP) is defined as a process of recognizing facilities on the construction site (Elbeltagi, 2011). Engineers have to specify and plan where to locate these facilities during the construction time. CSLP is mainly a duty of a project manager. Problems on the construction site usually happen due to the poor management rather than the performance of the workers. More studies from Elbeltagi (year) concluded that inefficient construction site layout is a primary reason why construction is unproductive. Although it is a very important process in the construction project, it is relatively paid small attention (Chau & Anson, 2002). Moreover, construction site layout is usually done by a sole decision maker (Tommelein et al., 1992). Engineers use their experience and rule of thumb to judge their decisions because there are no formal methods that can assist them. (Chau & Anson, 2002)

1.1.2 CSLP in Modern Real Practice

Nowadays, CSLP takes place in the first stage of the project. The engineer uses a map of the construction site to plan where to locate facilities. Then, he judges and makes decision based on his experience, rule of thumb, and common sense.

The sequence of the planning has four steps. First, the engineer confirms the objectives and constraints of the planning. Second, the engineer considers the facilities which will be placed on the site. Third, the engineer plans layouts that solve the objectives and constraints from the first step. Finally, the engineer assesses the best layout from the available ones (Ning et al., 2011).

However, CSLP should also consider other aspects, such as scheduling, construction method, man power, equipment, and financial planning. These aspects are usually not taken into consideration by engineer into his layout planning

(Elbeltagi, 2011). This results to difficulty and confusion, which leads to problems that may occur.

1.2 Problems related to construction site layout

There are numerous reports regarding problems that occur routinely. These problems affect construction productivity. Moreover, CSLP is not paid attention as a sufficient job. Numerous project managers place everything at anywhere they can by implementing the "First-come First-serve" method (Tam & Tong, 2003). Layout problems can occur with many facilities, such as materials, plants, and temporary structures. Consequently, these facilities are not optimized and affects the construction productivity which can lead to cost overrun. Some problems according to Elbeltagi (2011) are as follows:

1. Materials are located too far from hoist.
2. The tower crane cannot sustain all of the construction site area.
3. The mixer cannot be accessed by the aggregate delivering.
4. The site office is placed too near to a work place which makes loud noise so the engineers cannot work productively.

The effect occurs from the problem of the construction site layout does not only end with lower productivity but also affects the quality of the work, schedule, and cost to be overrun. Example of quantitative consequences of poor construction site layouts are as follows (Boussabaine, 1996):

1. 5 Man-hours per week are lost due to the congested work areas.
2. Equipment travel freely without anything to carry for 12.4% loss of day work.
3. Excessed traveling paths of equipment and material makes 4.6% of the day work lost.
4. Non-productive time due to the non-optimal site layout is stated around 7% of a day.

CSLP is hard to measure the quality of the planning. Although conflicts do not happen, it does not mean that site layout is perfect. Moreover, the project manager is not able to check or measures his layout. Therefore, he cannot evaluate and upgrade his skill (Cheng & O'Connor, 1996)

1.3 Problem Statements

1.3.1 Lack of precise CSLP knowledge

Site practitioners believe that the best way to understand knowledge on the construction site is through practice. They usually rely on the knowledge from physical objects, i.e., the experience from the trial-and-error on the field, more than abstract objects. Thus, it makes planning to be the hardest part in the construction process. (Sears et al., 2008)

There are limited ways to obtain the site layout planning knowledge. One of the causes is neglect of practitioners to CSLP. They believe that problems concerning construction site layout problem can be neglected and solved naturally when the construction advances (Sadeghpour et al., 2006). Moreover, some practitioners use "First-come-first-Served" method to deal with the facilities which might not be useful to produce knowledge (Elbeltagi, 2011). In addition, CSLP is a responsibility of the project manager which means that on-site engineers do not have to understand entirely about the reasons behind these decisions (Tommelein et al., 1992). Therefore, the knowledge is congested at the managing level which is hard for inexperienced personnel to achieve. However, Tommelein et al. (1992) stated that these managers were happy to share their knowledge if they had to.

1.3.2 Lack of guidelines established to suit modern construction project environment for the low expertise planners

Most of the literature about CSLP furnish a rough overview. For instance, The Social Housing Foundation (2006) indicates that there is no standard for the construction site layout and provides only some aspects which engineers have to go through. Some literature focus on precise on-site aspects which are hard for the low expertise engineers to catch the overview and understand the procedure they should follow. For instance, Mincks and Johnston (2010) provided precise knowledge for the construction jobsite management through many components on the field, but the low expertise engineers might be confused where to start due to its complexity. Finally, some studies lack some knowledge aspect. For instance, Bennett (2003) concentrated on facilities on the site without explaining the equipment management. Jackson

(2010) stated that the engineer has to beware of some factors, such as material storage handling, job site security, traffic control but does not focus greatly on the planning of the equipment usage. Wong et al. (2005) focused on the equipment and protection aspect but does not inform about the facilities treatment on the construction site.

From these shortages, a guideline of CSLP for low expertise engineers is needed. It has to be able to assist engineers from the start until the final stages of the planning. The reasons behind the suggestion are also crucial in order to make it clear for engineers why the decision should be chosen. Moreover, the guideline can be utilized to benchmark and cross check the existing construction site layout for the planner due to the shortage of CSLP standards.

1.4 Research Objectives

The main objective of this research is to propose the development of a system for CSLP. The knowledge base is constructed from the knowledge of the expert panel. This system can act as a consultant for low expertise engineers to be able to follow. Moreover, planners can also utilize the guideline produced from knowledge rule bases to benchmark with their existing site layouts for the potential improvement of their layouts.

The sub-objectives of this research is to examine the current real practices of CSLP in order to enhance the knowledge of the practitioners and form the guideline from knowledge rule bases of the system.

1.5 Scopes of Study

The system is developed to assist CSLP. The scopes of the study are as follows:

1. The knowledge behind the system construction is gained from the experts who have expertise in CSLP for at least ten years.
2. The type of the project which is focused is a high-rise building by the meaning in Building Act issued in 1979.
3. The buildings used for the knowledge acquisition is constructed by reinforced concrete.
4. CSLP knowledge is focused on the design phase.

5. The final system concentrates on components that experts locate on the construction site in the design phase

1.6 Expected benefits from the research

The expected benefit of the research is the system which can be utilized as assistance for CSLP of high-rise reinforced concrete buildings. The system is developed to represent the implementation of the expert panel on CSLP knowledge. Low expertise engineers can follow this system in order to manage the planning. Moreover, the planners can also utilize the knowledge rule bases to benchmark or cross check their CSLP for the possibility to improve their layouts in the design phase of the construction.

Chapter 2
Literature Review

2.1 Introduction

This chapter gives the summary of the literature relating to the research. Topics are separated into nine parts. These parts are (1) introduction, (2) components on the construction site, (3) factors affecting CSLP, (4) supporting system, (5) CSLP with the supporting system, (6) the usage of knowledge-based system in CSLP, (7) case study, (8) multiple case study, and (9) qualitative data analysis.

2.2 Components on the construction site

Elbeltagi (2011) specified 38 facilities on the construction site as shown in the Table 2.1. However, these facilities might not appear in every construction project. They vary from factors, such as construction projects, site constraints, and local regulations. The number of components on the site changes when the time passes. There are only 12 facilities presenting in the study of Cheng and O'Connor (1996)

Mincks and Johnston (2010) divided facilities that the planner has to prepare on the site into four groups. The first one is the material storages or laydown areas. The material storage used to store the material, such as steel, concrete, and goods of subcontractors. The next one is temporary facilities which have three sub criteria: jobsite offices, dry shacks, tool storages. The third group is sanitary facilities, for example, drinking water tank, washing water tank, and toilets. The last category is temporary utilities for the employee on the site, for instance, water, electricity, and weather protection.

Bennett (2003) focused on temporary services and facilities, storage/laydown area, security and signage, and quarries and borrow areas. For the temporary services and facilities, they are clustered into groups, which are (1) offices, (2) workshops and indoor storage, (3) dry shacks, (4) temporary housing and food service, (5) temporary utilities, (6) sanitary facilities, (7) medical and first aid facilities, (8) access and

Table 2.1 Facilities on the construction site (Elbeltagi, 2011)

Facility No.	Facility Name
1	Job office
2	Owner representatives office
3	Subcontractors office
4	First aid office
5	Information and guard house
6	Toilet on site
7	Staff/Engineer dormitory
8	Staff/Engineer family dormitory
9	Labor dormitory
10	Labor family dormitory
11	Dinning room for labor
12	Bathroom for labor
13	Restroom for labor
14	Equipment maintenance shop
15	Parking lot for mechanics
16	Prefabricated rebar storage yard
17	Rebar fabrication yard
18	Fabricated rebar storage yard
19	Carpentry shop
20	Storage yard for lumber
21	Storage yard for formed lumber
22	Cement warehouse
23	Batch-plant and aggregate storage
24	Craft change-house
25	Sampling / Testing lab
26	Pipe jointing yard
27	Pipe storage yard
28	Welding shop
29	Parking lot
30	Tank
31	Long term laydown storage
32	Machine room
33	Electrical shop
34	Steel fabrication shop
35	Sandblast shop
36	Painting shop
37	Scaffold storage yard
38	Material warehouse

delivery. The storage/laydown areas have to be managed systematically to reduce the confusion when they are needed. The inside of the building is also available to be utilized as the storage for the weather-sensitive material. The security and signage is important to the jobsite also. The site has to be separated from the outside due to the safety issue. The signage is useful for the construction site in order to inform employees and pedestrians about general and important information. Lastly, quarries and borrow areas are critical for developing sites. The waste from the construction can be dumped or rested either on the site or other places before the further transportation is done.

For the equipment, Hendrickson and Au (1989) separated them into 6 categories, which are (1) excavation and loading, (2) compaction and grading, (3) drilling and blasting, (4) lifting and erecting, (5) mixing and paving, and (6) construction tools and other equipment. The excavation and loading are equipment used to do the earthwork, for example, the bulldozer, crawler, and draglines. Second, the compacting and grading equipment usually relate to the work with soil elevation, such as infrastructure work. Third, the drilling and blasting equipment are heavy and durable in order to deal with the earthwork which contains stones, for instance, the tunnel construction that requires the penetration into rocks. Next, machines assisting the lifting and erecting in the construction project are tower cranes (both stationary and mobile) and hoists (both material and personal). They can be found frequently in building projects. Then, the mixing and paving equipment relate to the building construction and road works. The mixer can be either stationary or mounted with the trucks. Finally, construction tools and other equipment are, for instance, air compressors, pumps, and electrical machines.

2.3 Factors affecting CSLP

Numerous studies focus on the actual work on the jobsite and how to manage for each component on the construction site. Although the good planning in the first steps of the construction can assure the success of the project, small number of literature provide the overview of the aspects which relate to CSLP (Sears et al., 2008).

Nevertheless, Mincks and Johnston (2010) explained seven aspects which the planners have to keep in mind when they are doing CSLP. These aspects consist of (1) jobsite space allocation, (2) jobsite access, (3) material handling, (4) worker transportation, (5) temporary facilities, (6) jobsite security, and (7) signage and barricades. Mincks and Johnston (2010) further grouped the factors affecting CSLP into four divisions. The first one is the material handling which deals with the delivery to the construction site. The selected equipment must be prospered. All costs, availabilities, capacities, safety, quantity of materials, and accessibilities have to be concerned by the planner. The delivering must be convenient. Delivery routes and coordination of the destinations have to be specified clearly. The second factor is the labour productivity that is the most unpredictable. A major problem affecting the labour productivity is the distance a labour takes to reach the destination. For example, a worker would like to go to the toilet. If the distance from the workspace to the toilet is too far, the productivity will be dropped down because of the idle time when the worker spends to reach and go back from the toilet. The third aspect is equipment constraints. It concentrates on the point of the delivery, site accessibilities, sequences of the work process, and the location of temporary facilities which the equipment has to deal with. Finally, the last one is the site constraints. This aspect has the most powerful effect with CSLP. The construction site in the downtown area might be very cramp and requires high level of creativity. The traffic condition, the space for delivery vehicles, and queuing areas are encouraged to be planned beforehand.

Jackson (2010) paid attention on the work on the field more than the planning in the wide aspect. The literature separated factors into eight groups, which the management team has to take care. These factors are (1) material storage and handling, (2) job site security, (3) site access, (4) employee parking, (5) traffic control, (6) pedestrian safety, (7) location of cranes, and (8) miscellaneous facilities. The material handling usually bases on the laydown area. It is a locked place storing the material, such as beams and girders waiting for the calling to be used. Second, the job site security prevents hazards going outside of the site. The perimeter fencing, guard dogs, private security patrols, electronic alarm systems, and night watchmen are encouraged. The site access varies from sites to sites. Some sites might not face this problem, while, some sites might be a major problem. The employee parking can raise the morality of the people on the site. They do not have to try their luck in order to find the parking in the downtown area. Next, the traffic control can affect the productivity of the work site in the congested workspace. On the other hand, the pedestrian traffic has to be concerned also. Their safety can be protected with the cover over the walkway. Jackson paid attention to the location of cranes as one of the major aspects affecting the construction site. Height limitations, required ranges of horizontal jib, and needed capacities are factors that have to be thought of. Cranes when finished placing cannot be removed. Stationary ones are complex and cost huge expenses in order to be moved, so it is a good idea to plan wisely from the first phase of the construction. Finally, the miscellaneous facilities are the unusual tools and machines that are rarely utilized, for example, dumpsters, vending machines, and generators. However, all of these information are general and hard to assist the engineer to have a precise view of CSLP.

Hendrickson and Au (1989) gave general information about principles to plan for components on the site. The scope of the project specifies the type of site offices and storages. The area of site offices has to be adequate for the document and plans preparing. The location of site offices should be able to see the workspace, if it is possible. The toilet should be located near the workspace to decrease the idle time from the job. The storage must be secure from theves and should be placed near the delivery location. For the delivery location, access roads must be provided to the storages, the material transferring must be done as close as possible to the installation position. However, other minor components and equipment are not suggested.

The Social Housing Foundation (2006) provided a brief guideline for planners which are the access and exit point of the site, the circulation of the material, vehicles, and staff, positions of temporary services like electricity and water supply, and the position of the constructing building and temporary facilities. However, the building scope is a housing project which does not require the variety of equipment. Consequently, it can be generalise to building projects

From the literature review, it can be indicated that the factors affecting CSLP are numerous and vary from literature to literature. This problem can cause the planners to be confused and lead to the conflict in the planning. In order to gain the standard which represents the real practice, it should be developed from the knowledge of the practitioners who have the expertise for CSLP. Anyway, due to its complexity in nature, the reliable and systematical data collection is required before the guideline is presented, so that low expertise engineers can follow or the planners can benchmark their construction site layouts for the potential improvement.

2.4 Supporting system

A supporting system is a part of Artificial Intelligence. It can give an expert answer for a question in the domain of its knowledge. It is also described as heuristic, transparent, and flexible. Heuristic means it can give a conventional knowledge which has theories supported. Transparent means it can explain clearly why it recommends the answer. Flexible means it can sum its new learning with the old one (Buchanan, 1982).

Supporting systems were developed in the mid of 1960. The source of the system is added the expertise of human to be stored in the memorize unit of the computer. The main aim of a supporting system is assisting users who have no or little expertise in the knowledge domain of the system. When a user requests for advices, a supporting system will suggest by looking up in its storage and reply a proper solution based on the conditions given from a user as inferences. Then, it returns answers which responded to these inferences (Turban et al., 2005).

2.5 CSLP with systems

Sadeghpour et al. (2004) explained about the models which related to the construction site layout by drawing into a chart as showed in Figure 2.1.

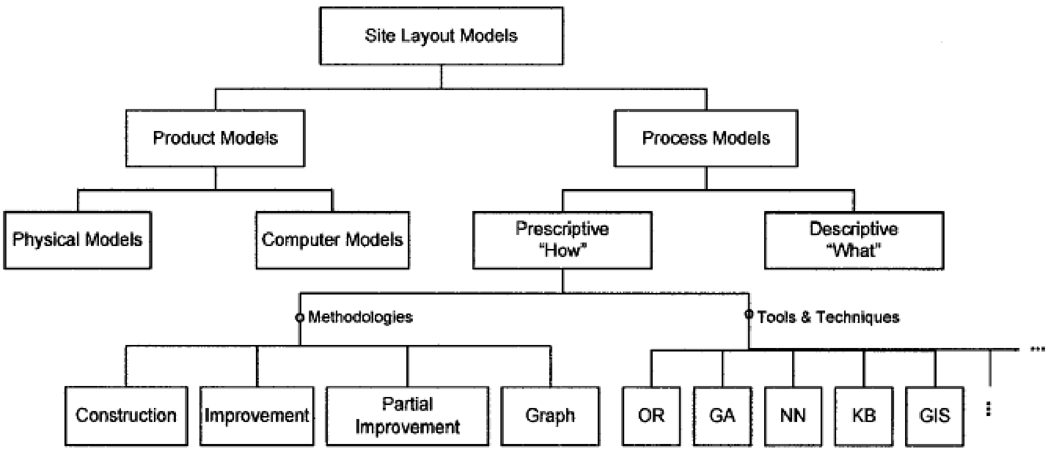


Figure 2.1 Chart of site layout models (Sadeghpour et al., 2004)

The first step of site layout models is separated into 2 categories which are product models and process models. Product models are presented for the purposes of visualization task to help the planners to get a view of the site layout due to the limitation that they cannot place all of the facilities on the site and move them directly. The physical models are drawings and templates of each facility. Drawing is the method which the planners draw facilities into the layout and consider the site whether it satisfies them. Templates are the cards which represent each facility so the planners don't have to draw and erase them on the drawing. CSLP is later introduced to the computer models which use computer to replace the manual objects for site layout planning. However, they don't give any knowledge about how to do the construction site layout.

Process models are the models represented the way that site layout should be implemented. Process models are divided into two parts which are the descriptive process and prescriptive process. Descriptive models tell the planners what they have to do by giving a list to follow. Unfortunately, descriptive models don't give numerous detail how to do the site layout in each step. Prescriptive models give the procedure how to do the site layout. The function in the model is concluded into two parts which are Methodologies and Tools & Techniques.

The methodology showed by Sadeghpour was divided into four types. Construction is the way the models try to reach the optimal site by placing each facility one by one and update the site layout before going to other facilities. Improvement works opposite the way the construction does by starting from the initial site and then moves the facilities to find the most optimal site layout which answers to the objectives. Partial Improvement stays in the centre of these two categories. Finally, Graph is usually used for the floor planning in architecture. It decides the pair of each facility by using graph theorem which the main disadvantage is that the optimal site layout might not be reached. (Sadeghpour et al., 2004)

About tools & technique in the last few decades, researchers who interest in CSLP always try to make a better layout as a main objective. They use systems to do CSLP since the work flows are the same in any project which suits to be calculated by the computer; Recognizing, Planning, and Placing. Moreover, CSLP also requires awareness, knowledge, and reasoning in order to solve the problem which systems can deal perfectly (Ilter, 2009). Types of the algorithm for the system are shown in the next topics

2.5.1 Hybrid Linear Programming

Zouein and Tommelein (1999) used Hybrid Linear Programming to minimize transportation and relocation costs. They specified 2 types of constraints to be used with the optimization formula. First, it is a “Hard Constraints” which are no overlapping, considering only the area in the fence, minimum range between two objects, and etc. There is another constraint called “Soft Constraints” which uses proximity weight to judge the quality of the site based on the distance between facilities and relocation weight to determine the difficulty of relocation of each facilities (Zouein & Tommelein, 1999). However, Linear Programing is too simple to be used optimizing the construction site layout problem which is a complex problem. Due to its simple calculation, it pays no attention to many aspects which are used to design a construction.

2.5.2 Genetic Algorithms

Genetic Algorithm is a method used to find the most optimal solution for many aspects of science, for example engineering, sciences, and researches based on procedure (Ripon et al., 2010). Genetic Algorithm represents itself as chromosomes carried a lot of decision variables. These chromosomes try to pair with another chromosome. However, genetic algorithm also reproduces the nature by approving of mutation to be represented in the program. The results are gotten from the pairing of variables in each chromosome. This implementation will continue simulating until the convergence is contented or reaches the specific rounds. The most suitable answers for all constraints will be chosen as the most optimal one (H. M. Said, 2010).

Genetic Algorithm has a lot of researches on CSLP compared to any other system type, for example, Chau (2004) proposed his application to do the optimization of CSLP by splitting the optimization into two parts. First, it is called “Lower-level Step”. In this stage, the optimization is done easily by linear programming from any applications. Origin, destination, and the transportation cost are determined to get the shortest path. Next, “Upper-level Step” is an optimization of every pair gained from the lower-level step to find the most optimal site layout. Extra costs which haven’t been calculated in the lower-level step, for instance, cost of shutting down the facilities and setting up at the new location, will be calculated in this step also.

Jang et al. (2007) proposed a Genetic Algorithm-based application to optimize the material layout on each floor of a building. The optimization formula is based on weight of the facilities and distance where the worker has to move these facilities between previous and next location. The application separates each floor to be a grid-like floor and assume each facility to be a square or rectangular to fit that grid. This research is one of the applications that can optimize the construction site layout through floors of the building.

Ripon et al. (2010) suggested a dynamic construction site layout optimization application by the concept of assembling all of the static site layouts in each time through the project. The application decides whether the facilities should be moved from site layout in one period to another period. If they have to be relocated, the transportation cost occurs. The main objectives are to sum the moving cost and handling cost over the site layout in each time. Moving distances, transportation costs, and fixed costs of facilities are considered in order to gain the most optimal site layout.

H. Said and El-Rayes (2013) proposed for another application which can optimize the area inside the constructed building. This application can help saving the area for packed construction site since it can use the area of unfinished floors inside the building as places where materials can be placed. It uses Genetic Algorithm to optimize two aspects which are transportation cost and project schedule criticality. Project schedule criticality is a factor to determine the impact on project schedule. It is calculated by using the float of each activity from the project schedule. There are four decision variables; (1) material procurement, (2) material storage plan, (3) layout of temporary facilities, and (4) scheduling of noncritical activities. There are other two constraints in optimizing the interior spaces of each room. First, it is called “Space Constraints” used to calculate the most feasible position of the facilities without overlapping or exceeding of the space condition. Second, “Interior Handling

Cost" is used to calculate for the cost spent to store the facilities in the building for a number of days before the next transportation time.

Genetic Algorithm is well-known through the scientific aspects and suits for complex optimization but it is hard for user who has no or little expertise to program an application to solve, requires high cost of computation with many variables, is not useful for the problem which nearly reaches the optimal answer, and might not find the global optimal point due to the premature convergence (Ripon et al., 2010), (Uzel, 2010).

2.5.3 Neural Network

Neural Networks are the procedure to solve conflicts by jointing the simple elements but concentrated on the relationships like neurons in human brain (O'Toole, 1990). However, neural networks have a major disadvantage which is the premature convergence. Yeh (2006) proposed SitePlan that consisted of another type of neural networks; Annealed Neural Networks. ANN combined both neural networks and simulated annealing which prevent the optimization to reach the premature convergence. SitePlan represented site layout as a set of rectangles which have equal size in each location. Then, it used n x n permutation matrix (n equals to the number of the facilities) to model the site layout which has facilities in each rectangle which can be placed anywhere on the site. Later, SitePlan formulated problem as the sum of construction cost and interactive cost and can be added other factors, for example, adjacency factors, distance between them, and availability of spaces. Anyway, the disadvantage of SitePlan are that it is hard to gather construction cost and interactive cost without human expertise and like GA, the users must have high expertise with the factors which ANN uses in order to gain the answer. The error from these factors can be a vital problem for the optimal solution (Sadeghpour et al., 2004).

2.5.4 Ant Colony Optimization

There are also some eccentric ideas about applying animal's behaviors into the optimization using system. Gharaie et al. (2006) proposed "Ant Colony Optimization" (ACO) which reproduced ants' behavior to solve the problem with CSLP. He stated that ants can always find the shortest path by using pheromone so he represented “Artificial Ants” in his program and sent them in every direction. Then, later ants follow a lead one like sensing the pheromone from the lead one. Finally, the program will find the shortest path by choosing the path which is left over and place the facility there.

Ant Colony Optimization has attractive method to solve the problem. However, there are a lot of disadvantages using Ant Colony Optimization. The main concern one is the coding. Coding for Ant Colony Optimization is very hard compared to any other types of optimization. Time of achieving optimal site cannot be guaranteed also. It might take long time before it finishes. Finally, it has difficulty to explain why the solution is the most optimal one (Abreu, 2011).

2.5.5 Geographical Information System

Geographical Information System (GIS) was utilized with a research of Su et al. (2012). The user has to give the grid-like shape of the construction site, work schedule, and the permanent facilities into the application. The application will calculate the following variables and substitute them into the optimization formula. First, the user has to input the convenience of the handling for each facility based on their sizes and shortest lengths from each one. Second, the convenience of delivery for each facility is required. GIS gives the cost in each grid after calculates values. There are two maps which GIS has to deal with; Storage map and Path map. Grids of the storage map represent the availability to be a storage by giving 1 to the grids which are available and 0 for the unavailable ones. Grids of the path map represent the way that the material should be delivered by sum up all of the eight grids around itself with its point in the storage map. Finally, the shortest path can be adjusted by considering from the values mentioned above.

The benefits of this program are that it can check the construction site layout to find the corruption with the work schedule and generate the optimal temporary facilities in the relocated construction site. The limitation is that it should not optimize only the area constraint but also other aspects. Moreover, Su suggested that this work should be used as an evaluation tool, not to be an optimization tool and should receive suggestion from the user also.

2.5.6 Knowledge-based system

Knowledge-based system inserted human knowledge into the application to let the computer be able to think like human. It is well-known in many experts, for example, medicine, financing, decision support, and management (Shu-Hsien, 2005). The four main parts of knowledge-based system are Knowledge Base, Knowledge Management System, Inference Engine, and Dialogue Subsystem (Wen et al., 2008). Knowledge Base is a component which the knowledge is input from expert's experiences. Wen encouraged using a format of "If-Then-Else" to represent knowledge in the system for an easier utilization. Knowledge Management Subsystem is a part which shows the explanation of the decision and gives reasons why users should follow the solution which a system suggested. Inference Engine searches through the knowledge rule-based to find the most proper rule and receives the fact from the knowledge base to calculate for the solution. After the solution is ready, it will show the fact of the current situation and advise for the solution. Finally, Dialogue Subsystem works to deposit input and withdraw output between a user and the Inference Engine.

2.6 The usage of knowledge-based system in CSLP

Knowledge-based system was encouraged to be implemented in the construction procedure since 1984 when Rehak (1984) proposed that it can be used in many phases of the construction project; Design, Interpretation, Planning, Monitoring, and Diagnosis. Knowledge-based system suits for the problems which require expertise, need decision making, and relate to black box scheme (Chau & Anson, 2002). However, it is not popular in construction aspects comparing with the other knowledge fields. The evidence is showed in the research of Shu-Hsien (2005) with Table 2.2. It does not have a notable study representing the construction aspect inside the table.

The reasons behind this were suggested by Rehak (1984), Tommelein et al. (1992), and Chakraborty (2010) as stated in the next pages;

Table 2.2 Knowledge-based systems and their applications (Shu-Hsien, 2005)

Knowledge-based systems/ applications	Authors
Medical treatment	Alonso-Amo, Perez, Gomez, and Montes (1995)
Personal finance planning	Dirks, Kingston, and Haggith (1995)
Engineering failure analysis	Graham-Jones and Mwllor (1995)
Waste management	Wei and Weber (1996)
Production management	Dawood (1996)
Thermal engineering	Afgan and Carvalho (1996)
Decision support	Keefe and Preece (1996)
Knowledge management	Dutta (1997)
Knowledge representation	Mitra and Basu (1997)
Framed buildings evaluation	Lu and Simmonds (1997)
Power electronics design	Fezzani, Piquet, and Foch (1997)
Financial analysis	Matsatsinis, Doumpos, and Zopounidis (1997)
Chemical incident management	Finch and Lees (1997)
Automatic tumor segmentation	Clark et al. (1998)
Business game	Duan, Edwards, and Robins (1998)
Climate forecasting	Rodionov and Martin (1999)
Agricultural management	Girard and Hubert (1999)
Steel composition design	Manohar, Shivathaya, and Ferry (1999)
Strategic management	Volberda and Rutges (1999)
Environmental protection	Gomolka and Orlowski (2000)
Wastewater treatment	Baeza, Ferreira, and Laufuente (2000)
Decision making and learning	Mockler, Dologite, and Gartenfeld (2000)
Isokinetics interpretation	Alonso, Fuertes, Martinez, and Montes (2000)
Chemical process controlling	Barrera-Cortes, Astruc, and Tufeu (2001)
Physical therapy planning	Tunez, Aguila, and Marin (2001)
Plant process control	Acosta, Gonzalez, and Pulido (2001)
Outage locating planning	Liu and Schulz (2002)
Concurrent system design	Mills and Gomaa (2002)
Case validation	Knauf, Gonzalez, and Abel (2002)
Chip design	Bourbakis, Mogzadeh, Mertoguno, and Koutsougeras (2002)
Agricultural planning	Cohen and Shoshany (2002)
Power transmission protection	Orduna, Garces, and Handschin (2003)
Crop production planning	Edrees, Rafea, Fathy, and Yahia (2003)
Tropospheric chemistry modeling	Saunders, Pascoe, Johnson, Pilling, and Jenkin (2003)
Urban design	Xirogiannis, Stefanou, and Glykas (2004)
Planar robots	Sen, Minambres, Garrido, Almansa, and Soto (2004)

- A lot of knowledge is tacit and hard to explain.
- Experts are important to many companies so they are very busy.
- Experts also aren't conscious about the solution they solve problems.
- Experts are afraid that computer will come to substitute them so they don't want to give the knowledge.

From the reasons above, the knowledge-based system in construction field is not popular much since it is hard to gather information because a lot of knowledge are complex, heuristic, and relate to black box scheme or rule of thumb. Moreover, the experts are busy with their works and don't have time to be interviewed. Anyway, there are also some notable knowledge-based e systems related to construction field especially in CSLP.

Tommelein et al. (1992) proposed SightPlan to assist the engineers in the power plant project. The function of SightPlan is divided into two parts. First, it is called "The domain knowledge sources" which suggests the program what to do next, for instance, lists all the facilities, select facilities to be placed, and calculates the optimal point between constraints. Second, "The control knowledge sources" takes the responsibility of controlling which procedures the program should do next. This source comes from the thinking of an expert which Tommelein called "Expert Strategy". "Expert Strategy" will be translated into "Computational Strategy" in later process by constraint engine. This constraint engine is a function to receive all of the constraints of each facility. The quality of the layout is up to the complexity of these constraints. However, Tommelein said that if there are too many constraints, the program cannot choose the place where is able to fulfil all of the constraints. Consequently, Tommelein separated constraints into 3 groups as follow to make the priority of constraints. Some might not necessary to follow;

- Early Commitment Strategy; It is the strictest constraints. Every constraint has to be fulfilled before placing the facility.
- Postponed Commitment Strategy; It is stricter than Least Commitment Strategy buy less strict than Early Commitment Strategy.
- Least Commitment Strategy; It is the least strict constraints.

After every facility is placed at optimal places, SightPlan will generate some alternative layouts which pass the “Evaluation Function” also and let the construction manager choose one which is the best layouts. Tommelein gave reason that although the program can generate the optimal layouts, the engineer should choose the most optimal one by himself because CSLP will produce the greatest success by the cooperation of the engineer and the assisting of the program. The result is showed in the Figure 2.2. However, there are huge disadvantages of this program. First, the input in SightPlan bases on only one specific type of the project which is the power plant construction. Consequently, it might not be implemented with other type of construction cases. Finally, it cannot generate reasons behind decisions. Therefore, it cannot produce abundant knowledge for the user who is interest in the planning.

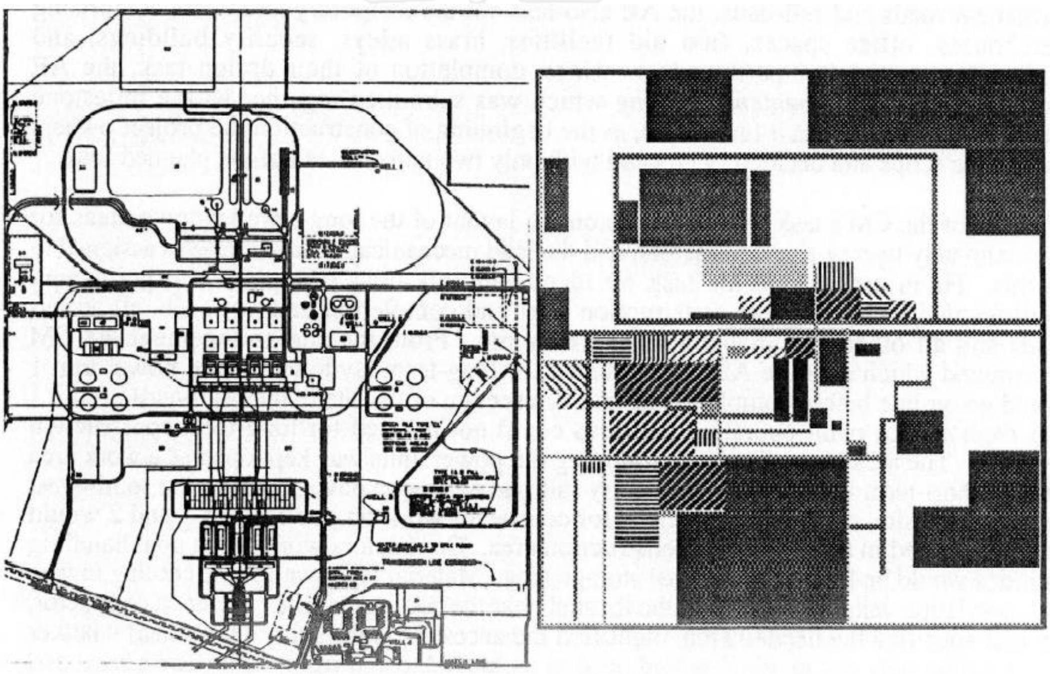


Figure 2.2 Result from SightPlan compares to the real site

(Tommelein et al., 1992)

Cheng and O'Connor (1996) proposed ArcSite which uses GIS and Knowledge-based to optimize the suitable site layout for the designer. They found that the knowledge about site layout is various from company to company and also from project to project. However, there are still some points which have the same implementing ways. Figure 2.3 below shows the procedures of knowledge acquisition and representation by collecting regulations, rule of thumb, knowledge, and experience into the knowledge base. After that, these knowledge bases are translated and saved in the knowledge representation. The knowledge base of ArcSite consists of four parts for each facility, which are (1) input, (2) knowledge acquisition, (3) knowledge base process, and (4) explanation facility. Input receives the constraints of the interested facility. Knowledge Acquisition obtains the knowledge. It is separated into five variables; (1) spatial, (2) distance, (3) adjacency, (4) position, (5) accessibility. The Knowledge Base Process translates the knowledge from Knowledge Acquisition and shows the reasons behind the decision. Finally, Explanation Facility gives the extra knowledge or recommendation for upgrading construction site layout. The example of Knowledge base of sanitary facilities is showed in Figure 2.4. Twenty-five facilities' knowledge is saved into ArcSite. The application was tested with Bull Run Steam Plant. The result is as showed in Figure 2.5.

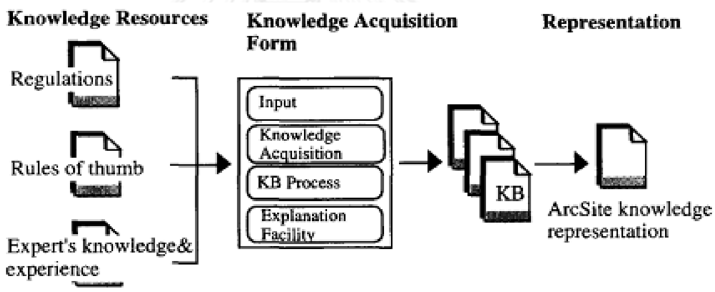


Figure 2.3 Procedures of knowledge acquisition and representation
(Cheng & O'Connor, 1996)

Chau and Anson (2002) presented SITELAYOUT which is developed by Visual Rule Studio application which is a sub application of Microsoft Visual Studio 6.0. SITELAYOUT uses "Plan-Generate-Test" strategy in order to achieve the optimal site layout with the knowledge base and object oriented system. SITELAYOUT's component consists of knowledge base, inference engine, and user interface as same as other knowledge based system. However, its knowledge base is stored in Microsoft Access which can be used as a library that collects knowledge from the real site layout planning, code of practice, and textbooks. The procedure of SITELAYOUT is making the facility first and then finds the constraints of that facility. Next, the

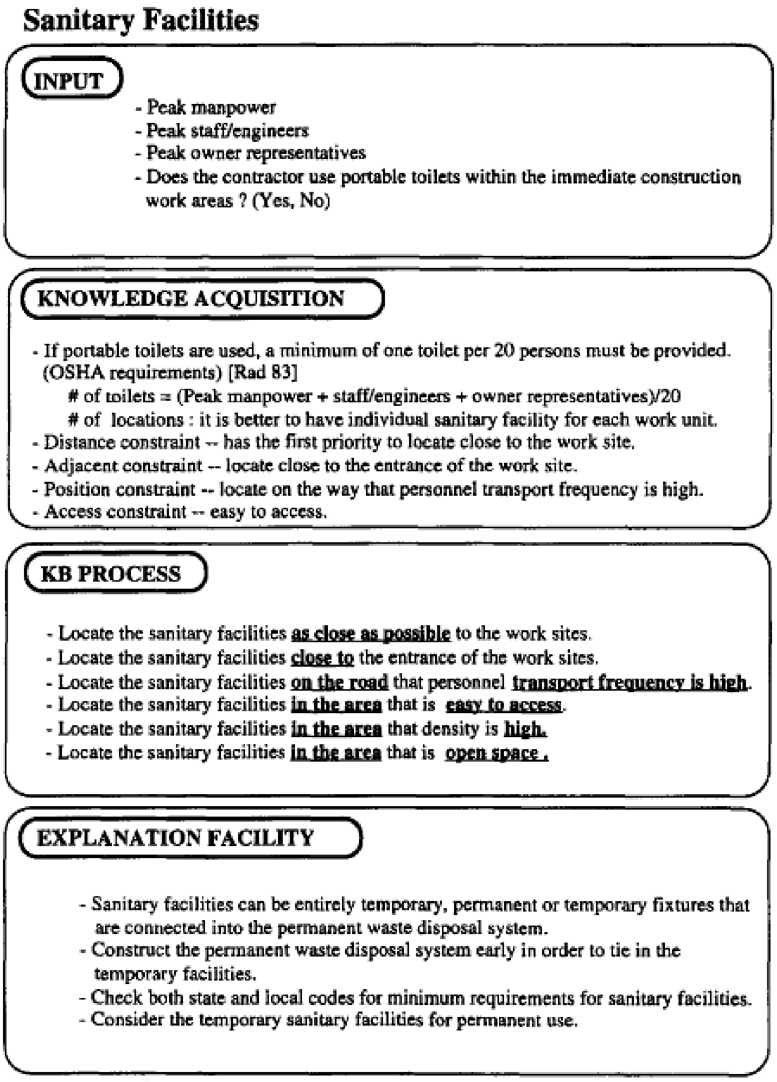


Figure 2.4 Knowledge base of sanitary facility (Cheng & O'Connor, 1996)

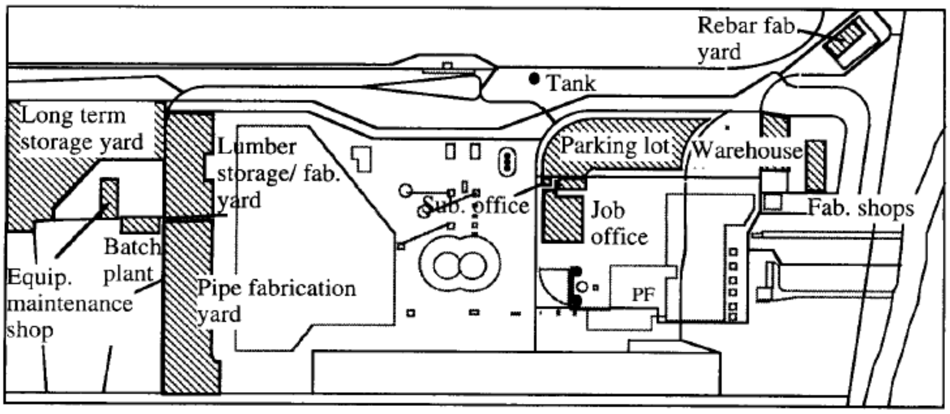


Figure 2.5 Final construction site layout (Cheng & O'Connor, 1996)

optimal location is pointed out. Finally, the facility moves to locate there. The interface of the application and result is showed in Figure 2.6.

The limitation of SITELAYOUT is that it cannot optimize as the overview of the planning like the real practice. The user has to place each facility one by one in order to finish the planning. Consequently, the first components do not get the influence from letter components. It also cannot display the reason behind the decision making.

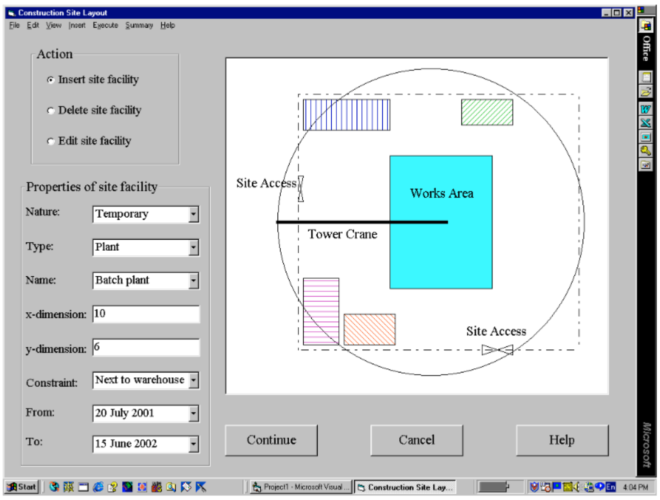


Figure 2.6 Result of SITELAYOUT (Chau & Anson, 2002)

2.7 Case study

A case study method is suitable for four types of situation (Jack, 2008).

1. When it is necessary to have the response from “how” and “why” queries.
2. The researcher cannot operate the study.
3. The factors behind the phenomenon are required to be known.
4. The studied circumstance is not clear.

It is a powerful tool to get in-depth information of the circumstances which the researcher cannot manage. It is suitable to solve for the “real world events” (McCutcheon & Meredith, 1993). The case study is usually conducted in many study fields, for example, nursing (Graneheim & Lundman, 2004), psychology (Campbell & Ahrens, 1998), and operation management (Raturi et al., 1990). It has numerous kinds of the case study type, for instance, explanatory, exploratory, descriptive, multiple case study, and intrinsic (Jack, 2008). These types have their own benefits which have to be specified. They must be chosen carefully to suit the nature of the phenomenon that has to be investigated.

In order to conduct a well case study research, McCutcheon and Meredith (1993) suggested the researcher has to understand the mechanism of the phenomenon or circumstance which is interested beforehand. The structured or open-ended interview can be conducted with the one who knows the phenomenon well. Observation is also important in order to interlink the knowledge between sources to gain more understanding. Distinctly goal, theoretical bases, carefully cases selection, and strong cooperation of the participants can produce a powerful source of knowledge. A case study research can be expanded to form a theory or new concepts up to the imagination of the researcher and accurate measurement.

McCutcheon and Meredith (1993) continued to explain how to construct a strong research design. The problems with the case study research can be separated into four concerns; (1) construct validity, (2) content validity, (3) internal validity, and (4) external validity, Construct validity focuses on which kinds of method the researcher chooses to be the core methodology. The measurement has to accurately respond to the real nature of the phenomenon. Content validity is the issue with the range of the questions used to ask to cover the level of interest in the domain. Internal validity is rising when the interpretation is unsound. The cause and effect must be clarified to be able to let other researcher to understand how the theories or knowledge were conducted. Graneheim and Lundman (2004) summarized these three factors into "Credibility" which the researcher has to think cautiously within his study. However, "External validity" or what Graneheim and Lundman (2004) called "Transferability" is the factor which the researcher has to question his findings that it can be applied to other environment. Due to the focusing of one case, transferability is usually a weakness of the case study research which the other researchers usually question.

2.8 Multiple case study

Due to the weakness of a single case study, a multiple case study steps in to rectify the disadvantage while keeping the advantages (Rowley, 2002). The multiple case study is a qualitative methodology that investigates more than one case. Not only it can raise the generalization of the study, but a researcher can study the similarities and differences among the various cases. It can guide the likelihood of finding the events. The analysis of such a methodology is challenging. It is usually grounded on examining, categorizing, and tabulating. There are no standards for a good analysis of a case study's data. However, the analysis should not create bias toward some aspects, and the analysis should still be able to use all of the significant evidence (Rowley, 2002). Nevertheless, the comparison is the heart of this research methodology. Consequently, the cases selection plays a vital role in this methodology. The researcher has to choose cautiously so the prediction can be indicated by the contrasts and similarities between cases (Yin, 2003).

A multiple case study is well-suited to CSLP problem because of its complexity in nature, gigantic amount of factors affecting the work environment, and numerous decisions that have to be made. The factors behind each decision can be seen through the similarities and differences between cases. Researchers with analytical tools can form networks behind these factors' relationships by "Flows" (Miles & Huberman, 1994) of the factors in each variable.

The example of the data collection for multiple case study is displayed in Raturi et al. (1990) about the forecast for the manufacturing of goods to sustain the harsh business environment. The study selected three companies which produced heavy machinery. Properties of these companies are similar in terms of costs of the product, manufacturing time, and variety of available goods. However, the size, the type of the company and the party of the owner are different in order to gather differences and similarities between cases. Interviewing with companies is conducted with the usage of a simple questionnaire to guide the flow of the talking. Anyway, the staff could give any information they would like to share. The data gained from the interviewing were submitted back to the staff to verify the correctness and fairness. Moreover, the researcher has to know the normal basis in the real practice to be able to get the synopsis from the interview.

2.9 Qualitative data analysis

Qualitative data is usually presented in words more than numbers. It makes qualitative data analysis to be in doubt for a long time because of its unclear procedures. Miles and Huberman (1994) argued that qualitative data analysis can be rigor by having systematic processes. They suggested that the study should have these methods in order to reach for the conclusion; (1) data reduction, (2) data display, and (3) conclusion drawing and verification.

Data reduction is the process which the researcher has to concentrate, select, simplify, and transform the enormous amount of information into the summaries, coding, clustering the theme, and writing memos. The data reduction can be done since the research starts until a final report is finished. Data reduction is also a part of data analysis. It is a process to use the research's decision to summarize, concentrate, discard, focus, and manage the data until it reaches the finish line of the final conclusion. Quantifying is also one of the qualitative data analysis, however, it is not a good idea to change every text to number. They should be presented together.

Data display is the second main process of the data analysis. It organizes, condenses, and constructs the information to be able to draw into the conclusion. By implementing data display, it can assist us to know what is going on and can reach to the decision of analyzing further or presenting. However, complex case studies, which have many variables to be justified, are complicated for the analysing and may lead to the wrong conclusion due to the low quality of human's processing performance. The data processing should be more precise by dividing the whole case studies into pieces of variables. By taking this action, it has more opportunity to discover the reasons and factors behind every decision made for these variables. Miles and Huberman (1994) suggested more that the better data displays are likely to lead to the valid qualitative data analysis. The displays include numerous methods to be utilized, for instance, graphs, charts, matrices, and flows. Data display is also a kind of data analysis, like data reduction. Choosing the cells from which columns and rows are analytic activities.

Conclusion drawing and verification is the third activity of the data analysis. It is the decision to know "What things mean". Nevertheless, the conclusion might be known vaguely since the study is started, but it will be clarified to be more grounded and reliable when the progress proceeds. In fact, drawing the conclusion might not be the last process of the study. It may be the start of the new data collection or return to the data reduction and display. Figure 2.7 shows the variables of data analysis presented by Miles and Huberman (1994).

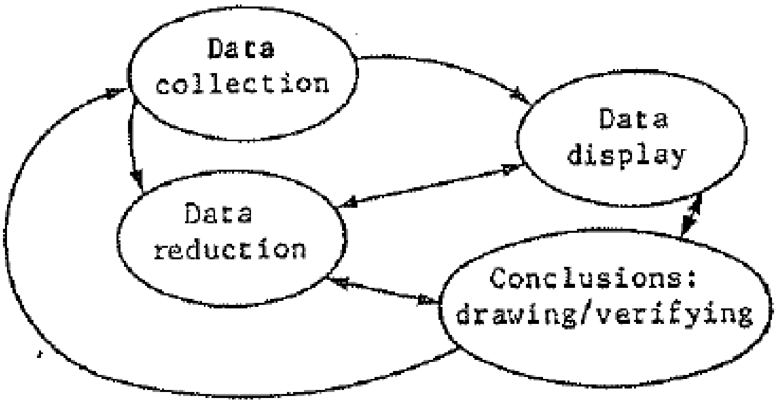


Figure 2.7 Variables of data analysis (Miles & Huberman, 1994)

By implementing multiple case study, they are numerous method to analyse the data. However, Raturi et al. (1990) presented the powerful procedure by processing the data in matrices and analysed through them. It is called tabular method. Table 2.3 shows the tabular method used by Raturi et al. (1990). Three firms are selected as cases for the study. They try to cope with the operation research which affected by the uncertain economic problems. From the table, it can be seen that each case have their properties filled into cells. After all of the cells are inserted, the similarities and differences between cases can be found through the table. This table is called "Summed indices". Nevertheless, the differences are prioritized to be analysed first because Miles and Huberman (1994) explained that studying from the difference is more likely to be able to reach the reason why the experts decide diversely than studying from similarities. Field notes, interview memo, and construction sites' data are integrated in order to interpret the meaning behind the decision making of the experts. The factors affecting the differences are sought to generate the conditions which alters the choices of decision makings. Finally, the framework is able to be drawn to assist the utilizer of this knowledge to gain more understanding and get the major overview of the processes, reasons, and relationship between units in the framework.

Table 2.3 Tabular method used by Raturi et al. (1990).

COPING MECHANISMS	COMPLEXITY REDUCTION						UNCERTAINTY REDUCTION					SLACK RESOURCES		
	PRODUCT DESIGN			PROCESS DESIGN			DEMAND MGT.		SUPPLY MGT.					
FIRM	Standardization	Design for Manufacturing	Modularity	Cellular Manufacturing	Ship set production	Setup time reduction	Selling to master schedule	Time fences for rework	Inventory of common options	Improved purchasing/contracts	Internal fabrication ability	Finished goods inventory	Engineering capacity	Production capacity cushion
COMPANY A Private				X	X	X					X	X	X	X
COMPANY B Public							X	X	X			X		
COMPANY C Public	X	X	X	X	X	X	X			X				

2.10 Conclusion

This chapter presents the literature related to the study. In order to do the CSLP, the planner has to recognize all of the components on the site. The necessary components on the site are varied from research to research due to the complexity of the work. Numerous factors have to be examined before CSLP is done in order to eliminate causes of risks. Unfortunately, it is unconventional for the planner to foresee all of factors affecting CSLP. Supporting systems are developed to assist the planner by this reason. However, the usage of the system might not represent the real practice. Consequently, problems can occur when the real practice begins.

From benefits and limitations of each type of systems, it can be observed that the knowledge-based system can act as the assistance for the user and create great advantages to CSLP. The aid from the system reflects the real practice which the user can follow and be able to understand what have to be done in order to achieve the good layout. However, numerous studies lack the knowledge displaying to clarify reasons behind the decision making which is not sustainable for the development of the knowledge for CSLP. The displaying of the precise knowledge from the system is needed for the education of new planners. They can understand the meaning of the decision better with the knowledge description. Moreover, the knowledge utilized to form the knowledge base inside the previous knowledge-based systems was based on limited sources. Consequently, these knowledge might be biased and lack transferability, which means that the system might not be usable with other construction projects. Systematical data collection and analysis are required in order to achieve the acceptable and general data so it can be implementable across projects in the same scope of the knowledge.

A case study is suitable for the questions which requires “why” and “how”. It can extract the knowledge and factors behind daily phenomenona. By investigating more case studies, factors affecting the interested circumstance can be found from the analysis of differences and similarities between cases. The data displaying plays the vital role in this process. A powerful data display can raise the likelihood to detect the knowledge from differences and similarities between cases. Tabular method used by Raturi et al. (1990) can be utilized with the study.

Chapter 3
Methodology

3.1 Introduction

The methodology is separated into 2 main phases: data collection phase and data processing phase. The data collection phase consists of 3 processes, (1) literature review, (2) exploratory interview and site investigation, (3) data clustering, and (4) multiple case study. The objective of this phase is to gather the information regarding CSLP from both the literature and real practice. The assembled data is transferred to the next phase, which is the data processing phase. In this phase, it consists of 5 processes which are (1) forming data tables of variables, (2) data processing, (3) data analysis, (4) data validation, and (5) system construction. Finally, a system validation is conducted with a case study to compare between the system gained from the research and the real practice. The flowchart of the methodology is shown in Figure 3.1.

3.2 Processes of the research

3.2.1 Literature review

Studies are reviewed to gather the important knowledge about construction layout planning. The literature can be categorized into two types, which are the implementation of CSLP and analysing methods. The multiple case study integrated with the summed indices is selected as the methodology due to its suitability with the question about the phenomenon that requires “why” and “how”.

3.2.2 Exploratory interview and site investigation

In order to understand the current real practice, the exploratory interview and the site investigation are established to gather more information. For the exploratory interview, eleven experts from different companies and dissimilar sectors have been interviewed. Each expert is asked about the procedures they implement with regard CSLP. The experts are provided a list of components from Table 2.1 of Elbeltagi (2011) to be a guideline if the experts cannot think of which point they can start off.

However, some of the components provided might either be lacking or exceeding from the real practice in nowadays. The experts can propose their opinions about which components are necessary to be added or deleted in the further procedures. All of the answers are noted and carried on to the next step of the study.

The site investigation is conducted to gain more detailed information from the real practice environment. Photography is employed by the acceptance of the staff to capture the actual CSLP and the environment on the construction site.

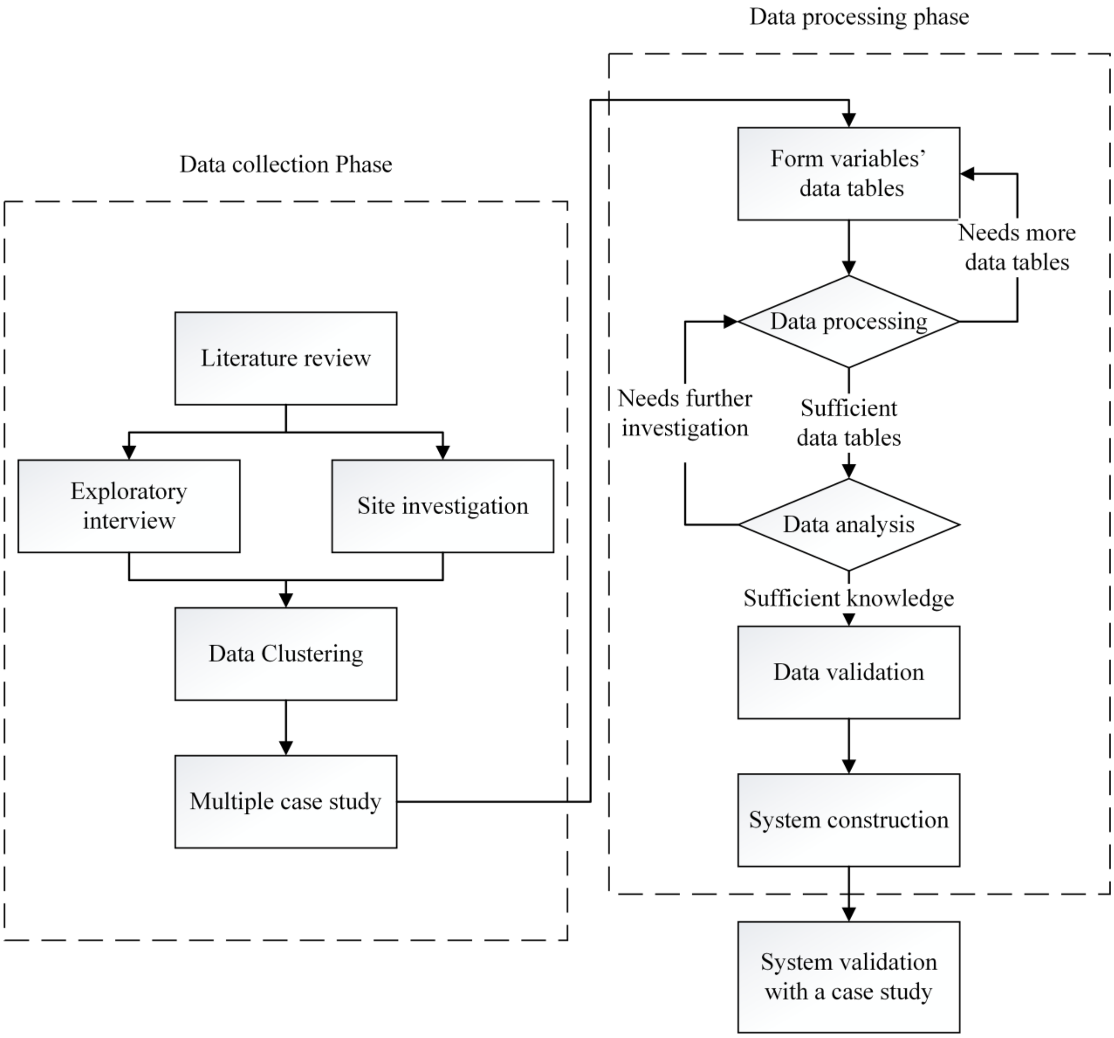


Figure 3.1 Methodology of the research

3.2.3 Data clustering

After all of the interviews and site investigations are conducted and the data from both parts are grouped base on the counting method. The same answers are calculated to justify the frequency of these interested work procedures. The tables of each variable's frequency are shown in the appendix. Photos from the construction sites are used to support the study's report in the further chapter.

3.2.4 Multiple case study

In this process, the multiple case study is conducted with the expert panel to gain the more in-depth information about CSLP. Every expert is proposed for a construction site layout that they have already finished their planning. Then, each expert is provided different construction cases from other experts. They have to manage CSLP for every other case by their expertise and knowledge. Figure 3.2 shows the methodology of multiple case study in this study. The expert panel is asked to clarify their decision making in order to eliminate the misinterpretation in the afterward procedure of the study. Every construction site layout is carried on to the analysis in the next steps of the study.

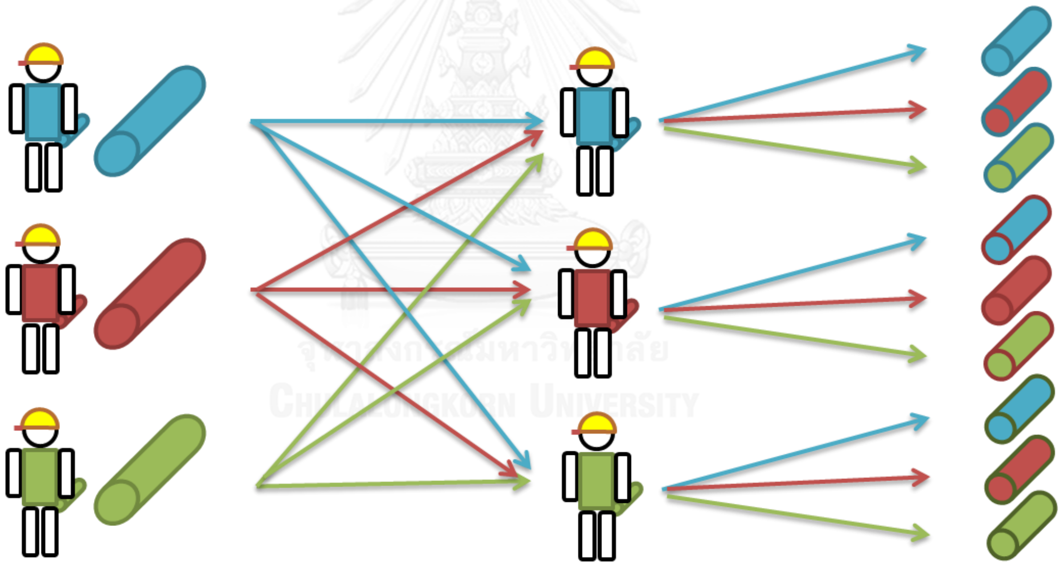


Figure 3.2 Methodology of the multiple case study in the this study

3.2.5 Form data tables of variables

In order to gain the knowledge from the real life problem, it requires a systematic data analysis to extract the knowledge out of a pile of information. Tabular method is chosen as a data processing method to display the similarities and differences between cases. The attributes justifying the similarities and differences are obtained from the answers after clustering of the exploratory interview. Each component has its own data tables for the later processing and analysis. However, the components which are carried on to the further steps have to be appeared in the majority of the cases done by the expert panel. The headers of these data tables are constructed by the attributes which experts used to justify their construction site layout for each variable in the exploratory interview. These headers are not fixed in which it can be corrected through the data processing and analysis to reflect the real practice at the highest level.

3.2.6 Data processing

When data tables are ready, the construction site layouts from the multiple case study are brought to be extracted the knowledge behind the planning. Each layout is subtracted into variables. These variables are separated and considered for their properties, for example, their locations, the method used to treat these variables, and types of these variables. Next, the data table is given ticks in the squares which represent the facts of these variables' properties in that layout case by case. The data tables which are filled by all of the information from every case are called "Summed indices". These summed indices are carried on to the next step of the study.

3.2.7 Data analysis

In this process, summed indices are considered for their patterns. The similarities and differences are analysed to find the factors and knowledge behind the decision makings. The summed indices can be compared between cases or within a case. The rule bases of the knowledge are formed initially, separated into factors, sub factors, condition to let the interested rule base happens, and the result of that rule base. However, a data validation is necessary to be managed in order to gain more reliability for these knowledge's rule bases.

3.2.8 Data validation

The data validation is conducted with experts who participated in the multiple case study step. All of the knowledge's rule bases are categorized based on the factor they belong to. This implementation supposes to assist experts to justify over a factor a time, so they can focus on an aspect only and concentrate on that factor better. Each expert is asked about their opinion on the rule bases whether these rule bases are correct. They can give the score in the 5-point Likert's scale which 5 means totally agree and 1 means totally disagree. If some of the rule bases gain the score lower than 4, it has to be corrected or removed from the knowledge's rule bases. Anyway, the rule bases which have score more than 4 might be modified after the suggestion from the expert panel also for making the knowledge's rule bases reflect the real practice as same as possible.

3.2.9 System construction

The validated rule bases are carried on to the next step of the study to form the system of CSLP. The guideline is conducted from factors affecting CSLP. It represents the workflow of the system. Input and value of factors trigger decision makings in order to reach suggestions from the system. The guideline can be utilized also if the user would like to study into the process of decision making from the system.

The core objective of the system is to assist CSLP based on the knowledge from experts inside the system. The user can follow through the suggestion made by the system. All of factors are required values to let the system calculate which knowledge rule bases are affected and needed to return the suggestion to the user. The concept of the system is presented in Figure 3.3.

3.2.10 System validation with a case study

A case study is managed to compare between the real practice and the research data. Knowledge rule bases are justified whether their conditions are responded to the condition in the case study. If the interested knowledge rule base is triggered, the knowledge inside the interest rule base is justified the similarity with the actual real practice on the site.

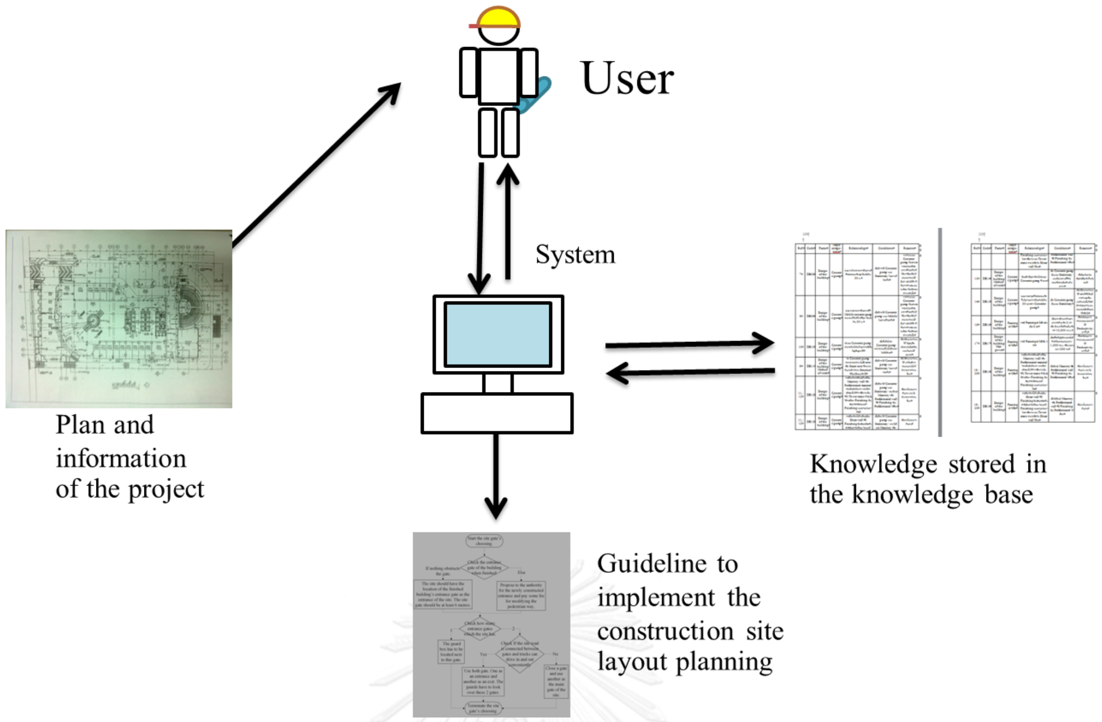


Figure 3.3 Concept of the system

Chapter 4
Data Collection

4.1. Introduction

This chapter presents the procedure used to obtain the current real practice of CSLP. First, experts who have the experience in CSLP for building projects are selected as the participants in the exploratory interview. The interview focuses on the knowledge and experience of each expert behind CSLP. The data are further summarized and clustered into themes of each component on the construction site. Next, the site investigation is conducted to explore the field practice. The investigation concentrates on the work procedure and problems with the construction site layout. Finally, the data collection and analysis are proposed to develop the conceptual knowledge for CSLP.

4.2. Overview of CSLP from expert interviewing

This study concentrates on the knowledge behind CSLP. The interview is implemented with experts who have expertise in high-rise building CSLP. In this case, high-rise building refers to Thailand's Building Control Act B.E. 2522. The high-rise building is a building with the height more than 23 metres. The interviewees are listed as shown in Table 4.1.

Every expert has expertise with high-rise CSLP equal or higher than 10 years. Most of the experts are project managers. Each expert is asked with the open-ended questions about CSLP to gain the overview of the real practice. The experts are free to talk about their experience with the planning, the process of work, and the principle of components managing on the site. Some experts might be oppressive if they have to think about all of the talking by themselves. Consequently, each expert is provided the list of components on the construction site layout from Elbeltagi (2011) as a guideline for their interview. They can follow the list to give their knowledge for those specific components, one by one. The list is shown in Table 2.1.

Table 4.1 List of all participated experts in the exploratory interview

No.	Type of Organization	Education	Position	Experience with the high-rise building CSLP (Years)
1	Contractor	Bachelor Degree	Director	30
2	Contractor	Master Degree	Site Manager	14
3	Contractor	Master Degree	Project Manager	10
4	Contractor	Bachelor Degree	Project Manager	45
5	Owner	Master Degree	Project Manager	10
6	Contractor	Bachelor Degree	Project Manager	20
7	Consultant	Bachelor Degree	Project Manager	24
8	Consultant	Bachelor Degree	Project Manager	15
9	Contractor	Master Degree	Project Manager	21
10	Contractor	Bachelor Degree	Project Manager Assistance	10
11	Contractor	Bachelor Degree	Project Manager	15

From the interview, it is discovered that the overview of CSLP processes from each expert are similar. They require the plan of the site and the design of the building. Then, they have to go to the real location to consider the environment around the site, for example, the neighbourhood nearby, the traffic around the site, and the obstruction on the site. However, the precise detail of each component is different. For instance, the tower crane is always used in high-rise building projects but the position might not be the same between projects. Some experts told that a tower crane should be installed in the lift core. Others might have a tower crane attached to the side of the building. Work method to implement with some components are also differed by experts. For instance, the sizing of steel yard is separated into two methods. On one hand, it is specified to store steel as great as possible. On the other hand, some experts manage the steel yard to store enough steel for the cycle of the work plan only. However, information from the interview is able to be clustered into groups, which means there might be some factors that the experts interpret and justify their decision in the same way with each other. All of the interview data are shown in the appendix A. On the contrary, the rest of the experts who do not think in the same aspect as the others must have some reasons which alter their decision also. If all of the knowledge, experience, and rules of thumb of each expert are revealed and summed together, the factors and the standard guideline for CSLP could be generated.

The critical indices of each component on the site are also collected at the exploratory interview. Table 4.2 shows all of the components and critical indices of each component. The scoring is based on the 5-score Likert's scale, The experts give five score to components which they think that it is significant for CSLP and have to be prioritized. On the other hand, if some components get one score, it means that the experts do not concern those components abundantly. The median of the data is used to justify the level of critical index of the interested components. The reason using the median instead of the mean because the nature of the critical index is in ordinal scales, and has little effect from answers which are totally different. (Student Development, 2009) It can be seen from the table that the entrance gate and the tower crane are the most two important components for the planning. The concrete pump, the passenger lift, the site office, the steel yard, and the store follows with the critical indices of four. Next, most of the components lay at the three score of critical index, including the mobile cement plant, the toilet, and the laydown area. These critical indices can be implemented with the data from further processes.

4.3. Current real practice of construction site layouts

After interviewing, the site investigation was conducted to gain more information of the real practice. The objectives are to inspect components of the construction site layout in the real practice and to search for problems related to the construction site layout. The result after the site investigation finished is shown in the next topic.

4.3.1. Components of the construction site layout in the real practice

Components found from the construction sites investigation can be divided into three groups which are equipment, facilities, and storage yard.

Table 4.2 Components and their critical indices from the exploratory interview

Components	Ex . 1	Ex . 2	Ex . 3	Ex . 4	Ex. 5	Ex. 6	Ex. 7	Ex. 8	Ex. 9	Ex. 10	Ex. 11	Q1	Median	Q3
Entrance Gate	5	4	5	5	5	5	4	5	3	4	4	4	5	5
Tower Crane	3	5	3	5	4	4	5	3	5	5	5	3.5	5	5
Concrete Pump	3	4	4	5	4	4	5	4	3	5	5	4	4	5
Passenger Lift	2	4	5	5	4	4	5	3	4	5	4	4	4	5
Site Office	5	4	4	5	1	2	3	5	4	3	1	2.5	4	4.5
Steel Yard	3	4	4	5	4	3	3	3	4	4	5	3	4	4
Store	3	4	5	5	3	3	4	3	4	3	4	3	4	4
Cement Store	3	3	5	3	3	3	4	3	3	4	4	3	3	4
Trucks' Tires Washing Yard	2	3	3	5	4	3	3	2	3	4	4	3	3	4
Fabricated Rebar Yard	3	1	1	4	4	3	1	3	4	4	1	1	3	4
Temporary Transformer	3	4	4	5	3	3	3	4	3	3	5	3	3	4
Toilet	4	4	3	5	3	2	2	3	1	3	2	2	3	3.5
Mobile cement plant	3	5	4	5	2	1	2	1	3	3	2	2	3	3.5
Guard House	3	3	1	4	5	2	1	5	2	1	3	1.5	3	3.5
Waste Chimney	2	3	4	5	3	2	3	3	2	4	3	2.5	3	3.5
Laydown Area	3	2	3	2	3	3	3	3	3	2	3	2.5	3	3
Formwork Storage Yard	2	3	4	4	2	3	2	3	3	3	3	2.5	3	3
Water Tank	3	3	1	5	1	2	2	4	2	3	3	2	3	3
Welding Shop	2	5	4	3	1	1	1	3	3	3	1	1	3	3
Service Workshop	1	3	2	1	1	2	1	3	2	3	1	1	2	2.5
Parking Lot	5	1	1	2	1	1	2	1	4	3	1	1	1	2.5
Fabricated Formwork Yard	2	1	4	1	1	1	2	1	1	1	1	1	1	1.5

4.3.1.1.Equipment

Equipment assists the construction directly. The experts have to specify the suitable equipment to support the construction precisely. The infeasible equipment can produce loss to the project because the expense for the equipment is the main cost of the construction. (Sears et al., 2008) The optimal equipment can increase the productivity, reduce the time, and provide safety to the site. The types of equipment which are usually seen on the construction site are shown in the next page.

4.3.1.1.1. Tower crane

The high-rise building construction project usually have this equipment on the site. It can assist many works, for example, transporting the material, aiding the uninstalling of the column formworks, and pouring concrete by bucket. Installation of the tower crane is vital to the construction site work progress. When the tower crane is placed, it has to be located at that position until it is uninstalled. Relocation of tower crane is not feasible. It takes time in order to remove which leaves the site without tower crane for a period of time. It costs major amount of money to construct the foundation of the tower crane, especially if the experts do not plan from the excavation of the project. The principle of the tower crane management is varied from sites to sites. Sizes, locations, and types of the tower crane are the properties which alter the construction site layouts to be different. Sizes of the tower crane are varied with the amount of five metres, for instance, thirty, thirty-five, and forty metres. The location can be separated into two major types, which are, in the building and outside of the building. It can be continuously divided into two groups for each major category. The principle to put the tower crane inside the building is parted to be placed in the lift core and blocked the floor. While, principles to place the tower crane outside of the building are next to the building and stand alone. The type of the jib is justified by the ability to support the transportation work on the site. The border of the site is also a factor for the jib type selection.

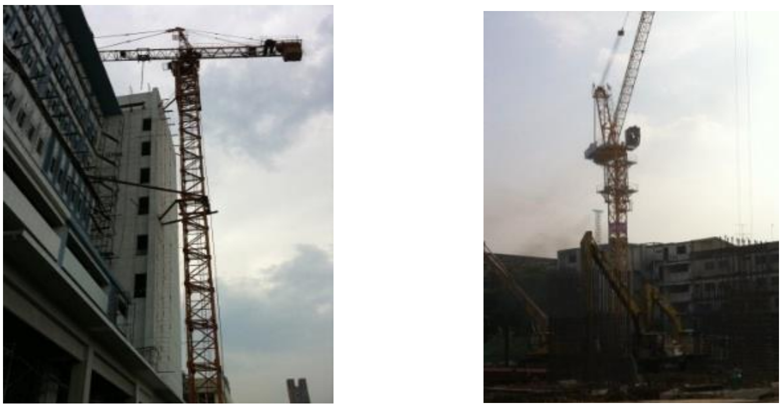


Figure 4.1 Different types of the tower cranes: fixed jib and articulated jib

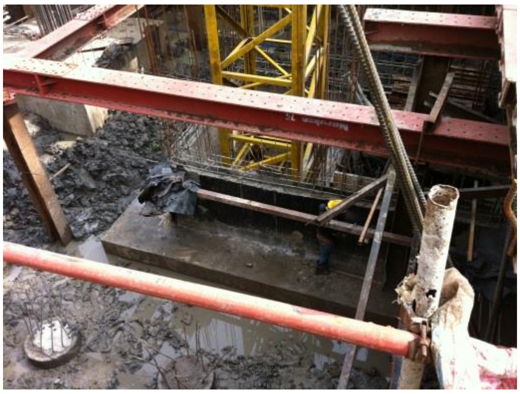



Figure 4.2 Different locations of the tower cranes: attached to the building and located in the lift core

4.3.1.1.2. Concrete pump

Due to the increasing of the construction project’s size, the concrete mixing by the labour on the construction site is not feasible for high-rise buildings. It has low productivity. Moreover, the quality of the mixing is also an issue. The poorly concrete mix leads to the low-strength concrete and does not reach the qualification of the designer. These reasons support the using of ready mix concrete service to become popular. It can control the strength and guarantee the quality of the mixing by the supplier. However, pouring the concrete in the high elevation is also a problem for the contractor to solve. One of the pouring methods is the using of the concrete pump. There are two types of concrete pump: Static and mobile. The static concrete pump is placed at the specific location. After the concrete trucks pour the concrete into the pump, the concrete is pumped through the pipe to the upper floors and released at the placing boom at the destination. The position for the static concrete pump can be chosen by three principles, which are, close to the building, close to the lift core, and close to the site road. On the other hand, the mobile concrete pump is a truck combines with the pump on the back. The mobile concrete pump can go around the site, however, its placing boom cannot shoot the concrete at great height. Finally, the principle to choose the type of the concrete pump is the accessibility of cement trucks to the pump and the free space where trucks can park. If cement trucks have free space to park and location to turn their back to the pump, the static concrete pump can be utilized.

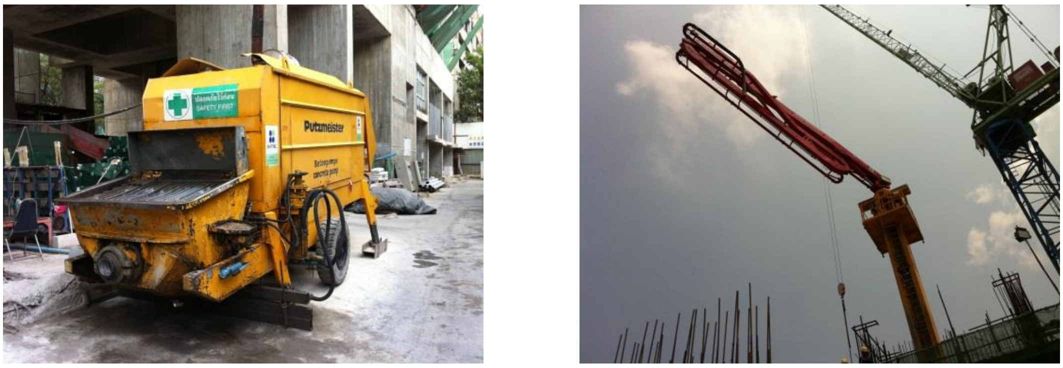


Figure 4.3 Static concrete pump and placing boom

4.3.1.1.3. Passenger lift

For the high-rise building, passenger lift can increase the overall productivity of labours. It can deliver labours in the vertical axis to the destination floor, so they can start their work faster and work longer without fatigue from the travelling to the workspace. The principle treating the decision for passenger lifts can be clustered into three types. First, experts use a pair of passenger lifts as a rule of thumb. Second, the work space of the building is compared with the number of passenger lifts before the selection. Lastly, the shape of the building affects the number of passenger lifts also. The location of passenger lifts is also separated into three groups. First, passenger lifts are place at the wall which can be finished later or does not have to be beautifully decorated. Next, the transportation comes in to be the factor affecting the choosing. Passenger lifts can be located at the place where they can transport conveniently. Finally, passenger lifts can be placed at the place where does not interfere with other work or equipment.

Figure 4.4 Passenger lift

4.3.1.1.4. Mobile cement plant

The mobile cement plant is the component supplying the concrete usage on the construction site. The mutual consent between the contractor, owner, and supplier must be reached before the installation. It consists of concrete silo and the stock pile of sand and gravel. The contractor can order the concrete whenever the work plan specifies. The supplier can also deliver the concrete to the customer nearby. However, it requires gigantic space and numerous procedures to take care of it, which the planner has to think carefully before using mobile concrete plant. Possible locations for the mobile cement plant are at the corner of the site and far away from the construction area. However, some experts also mention that it should not be placed on the site.

Figure 4.5 Mobile cement plant

4.3.1.2.Human-related facilities

Construction site is not a place with the equipment and the building only. There are works behind the construction, for example, preparing document for the contract and plans, making purchasing orders, and meeting between parties. Moreover, the staff on the site also have to get the normal welfare like other work environment, for instance, personal workspace and toilet. The facilities which relate to the human on the construction site layout are shown in this section.

4.3.1.2.1. Site office

The site office is the brain of the construction site. It is the work place for the engineers and other staff. The plans and strategies are brainstormed here and command to the field. The site office contains stationary like computers, tables, desks, shelves, and printers inside. It can be constructed by two methods from the site investigation: Newly build and prefabricated. The engineers prepare the shop drawings, work plans, and progress presentation on the site office. They hold the meeting in the meeting room once a week between the contractor, subcontractor, and consultant. Some construction site also has the site office for the owner representative and subcontract. The size of the site office is often calculated by the number of staff multiplied with the area per staff. Some experts give more information that specifications from the owner also acts as a factor affecting the size of the site office. The location of the site office varies from sites to sites. Majority of experts explain that it should be located at the front of the site. However, other experts give overview suggestions about the location, for example, places where do not interfere with other work, engineers can come to check the work conveniently, engineers can see all around, and moved into the building when the construction progressed. The site office has to be separated into three or more offices based on parties who use them. These parties are the owner, the contractor, the consultant, and the subcontractor.

Figure 4.6 Different types of site office: newly build site office and prefabricated site office

4.3.1.2.2. Toilet

Toilet is a standard sanitary facility on the construction site. It is a daily activity which every human has to go through. From the site investigation, there are two basses of toilet management. First, the staff toilet is installed within the office, while the labour toilet is located outside. Second, both toilets for the staff and labours are located outside but still be separated. The position of the labour toilet is various based on the planner. If the planner would like to support the workflow, he will place the toilet near the constructing building. However, that implementation is hard to do the safety management, so some of experts agree to place the toilet far away from the construction area and at the shrink or next to the wall of the site.

Figure 4.7 Toilet on the construction site

4.3.1.2.3. Store

Small equipment and materials are kept in the store. The labours or foremen come to get them and sign their name as the evidence before going to the work place. The store can use this document to manage the stock to sustain the work plan. If anything needs to be resupply, the keeper can contact the site office to make the purchasing order. The available locations for the store are near the site office, next to the constructing building and next to the guard box. The store can be both constructed by newly built method and prefabricated material.

Figure 4.8 Store on the construction site

4.3.1.3.Storages

The last type of components on the site is the storage yard. It is different from other component’s type because its dimension is not fixed. It can be either enormous or compact due to the planning. However, due to the variation of the size, it can cause numerous problems to the construction site layout if the planning and managing are not effective.

4.3.1.3.1. Steel yard

Steel is one of the crucial materials for the high-rise building construction. Engineers must calculate and prepare the steel in the amount that would be ready to be used through the work plan at all time. The process of the purchasing takes time which the planner has to plan carefully not to stock excessive steel in the cramp construction site and not too less to delay the work progress. The steel yard sometimes includes the fabrication equipment inside to bend or cut the steel, so when the schedule is reached, these steel is ready to be installed. The location varies from next to the fabricated rebar yard, the site road, and the construction area. Anyway, the main attribute which numerous experts concern is the accessibility of tower cranes and trucks. They both should be able to access the steel yard to support the transportation work.

Figure 4.9 Steel yard on the construction site

4.3.1.3.2. Laydown area

Laydown area is a place to store both short-term and materials, for example, rock, sand, bricks, and cement bags, and also long-term, for instance, architectural goods and supplementary material for construction. The delivery trucks drop these materials off and go out of the site. The laydown area is required great management in order to maintain the modesty. The poor management leads to the mess of laydown area and the contractor cannot utilize it at its full potential. Consequently, it will affect the short of storage area and job site safety. The laydown area also has numerous places to be located. The front of the construction, next to the store, and free space on the site are normal places that the laydown area can be settled.

Figure 4.10 Laydown area on the construction site

4.3.2. Problems with construction site layout

From the site investigation, there are some complications relating to CSLP. These are the example of the problems.

4.3.2.1. The storage yard has poor management.

This is one of the problems which can be seen in numerous construction sites. Enormous amount of materials, steel, and precast concrete are placed on the site without the well-planned management. This problem also spotlighted by Tam and Tong (2003). Some of the engineers treat the storage yard by "First-come-first-serve" method which leads to the disordered storage yard. The materials in the deep position are arduous to be moved, and the delivery trucks cannot reach the destination. Moreover, this problem decreases the safety level on the site. The labours who trespass into this untidy storage yard might hurt themselves from the falling and getting themselves cut.

4.3.2.2. The construction site does not have space for the parking of delivery vehicles.

This problem usually occurs with the construction sites which are cramp or has limited space in front of the site. The delivery trucks or cars have to park outside of the construction site, which can causes a traffic jam during the parking. Figure 4.12 shows the problem.

Figure 4.11 Untidy laydown area on the job site

Figure 4.12 Delivery vehicle parks outside the site and causes a traffic jam

4.3.2.3. The tower crane cannot support the stock yard.

Tower cranes can support numerous jobs on the site as mentioned in the previous section. However, the stock yard sometimes cannot access the tower crane because the tower crane is installed too far or the stock yard is located in the place where the tower crane cannot reach. This problem causes the transportation to be inconvenient and not productive. The contractor has to consider other method to transport these materials or tools. From figure 4.12, labours have to move the material by force and takes extensive time in order to finish the transportation.

Figure 4.13 Stock yard where the tower crane cannot reach

4.3.2.4. The toilet is located at the side where has pedestrians and other neighbours.

The labour toilet has strong odor, which can disturb other neighbours. It can be the origin of the conflict with the surroundings. The contractor should consider this risk and eliminate it.

Figure 4.14 Toilet is located at the side that has a neighbour

4.3.2.5. Space on the site is not managed at its full potential.

Due to diverse studies, space on the site is very essential. The planners have to manage wisely in order to use each space optimally. However, there are some free spaces on the site which can be employed but they are left behind. These spaces become desert places and cannot be utilized.



Figure 4.15 Lift core and some free space which cannot be utilized

4.4 The process of constructing conceptual knowledge

In order to get an optimal construction site layout, the planner has to be farsighted and has numerous knowledge and experience. The planner has to foresee the further work procedure and problems which can occur. Then, he can plan beforehand to support the work procedure and eliminate risks. Especially, the planning in the first stage of the construction project is very essential. Diverse components on the site cannot be moved due to the complexity and cost of the installation.

The plan of the construction site is crucial for CSLP. It represents the real job site before the construction takes place. It consists of the area which the planner can utilize and the boundary between the constructing building and job site. However, it does not mean that every planner who receives the same plan will design the same construction site layout. There are numerous factors on the construction sites which affect the site layout and every planner has their own aspects of planning. Consequently, they interpret these factors in different ways due to their knowledge and experience which can lead to the loss or profit of the construction project.

From the interview, it can be seen that the precise detail of CSLP has various contradictions due to the planners' aspects. Each expert gives the opinion base on the high-rise construction environment which they are familiar with. Therefore, it is complicated to reach the summation of the knowledge from these "General" answers. By this reason, the standard construction projects are required in order to let the experts be able to have the same aspect with each other. Then, the answers from experts can be compared and justified factors behind the similarities and differences. On the other hand, the knowledge from the literature review is explained in the general aspect which requires the decision to be made by the planners. It does not specify the detailed implementation of the components on the construction site. This circumstance can lead to the difficulty of CSLP when the planners have less experience.

From the site investigation, it is revealed that there are some problems on the construction sites. Each site has their own conflicts which occur and do not occur vary from sites to sites. Moreover, the pattern of the components on the sites also differs from sites to sites with similarities and differences. This issue happens because the planners treat the factors affecting the site layout in different ways. About the problems, some planners give the idea that they are not grand topics because the work can still progress. However, in fact, the quality of the site layout reflects the productivity of the construction project. The better performance of the site layout can raise the productivity and reduce the accident rate (Sanad et al., 2008). Besides, CSLP is usually done by only a person or a small group of people, which is difficult to produce the better result because there are no discussions or benchmarking between solutions. It is complex to know which explication is more desirable if there are no other explications as benchmarks.

After summarizing all of the data, CSLP requires enormous experience to be able to understand and justify countless factors affecting the site layout. However, it is complicated for a sole planner or a small group of engineers to catch all of the necessary factors due to the limitation of knowledge and experience in some aspects. Another problem is that CSLP lacks the discussion between other planners, results in the ignorance of the planner whether he has done a well planning. Sites which do not have problems occur do not mean that site layouts are perfect. These problems lead to the idea assisting CSLP by condensing all of the knowledge from experts through the real construction projects. By using the real construction sites integrated with the knowledge of experts, similarities and differences can be investigated between each construction site. This method is called “Multiple cases study”. These data can be analysed through qualitative data analysis to find the factors behind experts’ decisions. Finally, all of the factors can be summarized into the guideline and processed into a system as a tool to represent the overview of CSLP and let the planners be able to follow more convenient.

4.5 Expected benefit

The planners can know the overview of CSLP from the integration of the data from experts. They can know the necessary factors which they have to consider making the decisions for CSLP. Moreover, the planners can be assured that the knowledge is reliable because it came from the summation of numerous cases through the systematical data analysis.

4.6 Conclusion

In this chapter, it is separated into two main parts: Experts interview and construction site investigation. First, the experts are questioned with the open-end queries about CSLP and the components on the construction site. The interview indicates that the process of CSLP is similar between each expert, anyway, the precise detail about how they plan for each component are different due to the personal knowledge and experience. Second, the construction site investigation is conducted. The result shows that there is a variety of components' management as the interview indicated. The examples of conflicts on the construction sites are also revealed.

From the information mentioned earlier, it leads to the proposal of the knowledge integration for assisting CSLP. This knowledge comes from experts who have expertise in building construction by providing them the real construction projects and have them manage CSLP based on their experience. After that, these similarities and differences in each construction site layout are summed through the qualitative data analysis. The result from the analysis can be treated as a guideline for the planners who have low expertise or would like to benchmark their construction site layouts.

Chapter 5
Methodology and Knowledge Acquisition

5.1 Introduction

This chapter shows the methodology used to acquire the knowledge. In order to gain the reliable knowledge about the construction site layout planning, the appropriate data collection and analysis are required. First, the exploratory interview was conducted to gain the overview and general procedures which are implemented for each component in the construction site. These procedures are used as the criteria to justify decisions in the later phases. Next, the multiple case study is selected as the data collection because of its ability to provide in-depth information of the phenomenon from the real practice. Every site is planned by the expert panel and classified by the procedures in the first step. These data can be investigated further to find the factors affecting decision makings in each case by analysing through the similarities and differences between cases. Then, rule bases are formed from the interpretation of facts behind the decision making. These rule bases are submitted back to the expert panel to verify the correctness of them. Finally, the factors affecting the construction site layout planning and the knowledge behind the working procedure are filtered from verified rule bases to form the guidelines for assisting the construction site layout planning. The research procedure in this chapter is shown in the Figure 5.1.

5.2 The usage of the data from the exploratory interview

The data from the exploratory interview is used as the initial header of the data summarized tables for each variable. For example, Table 5.1 shows the location which the experts told that they are suitable for the site office. The headers are modified later to reflect the decisions of the experts from the multiple case study. Each component in the construction site has their own tables which will be processed by the data from the multiple case study. However, some components might be removed out of the further data analysis if it does not appear in the multiple case study

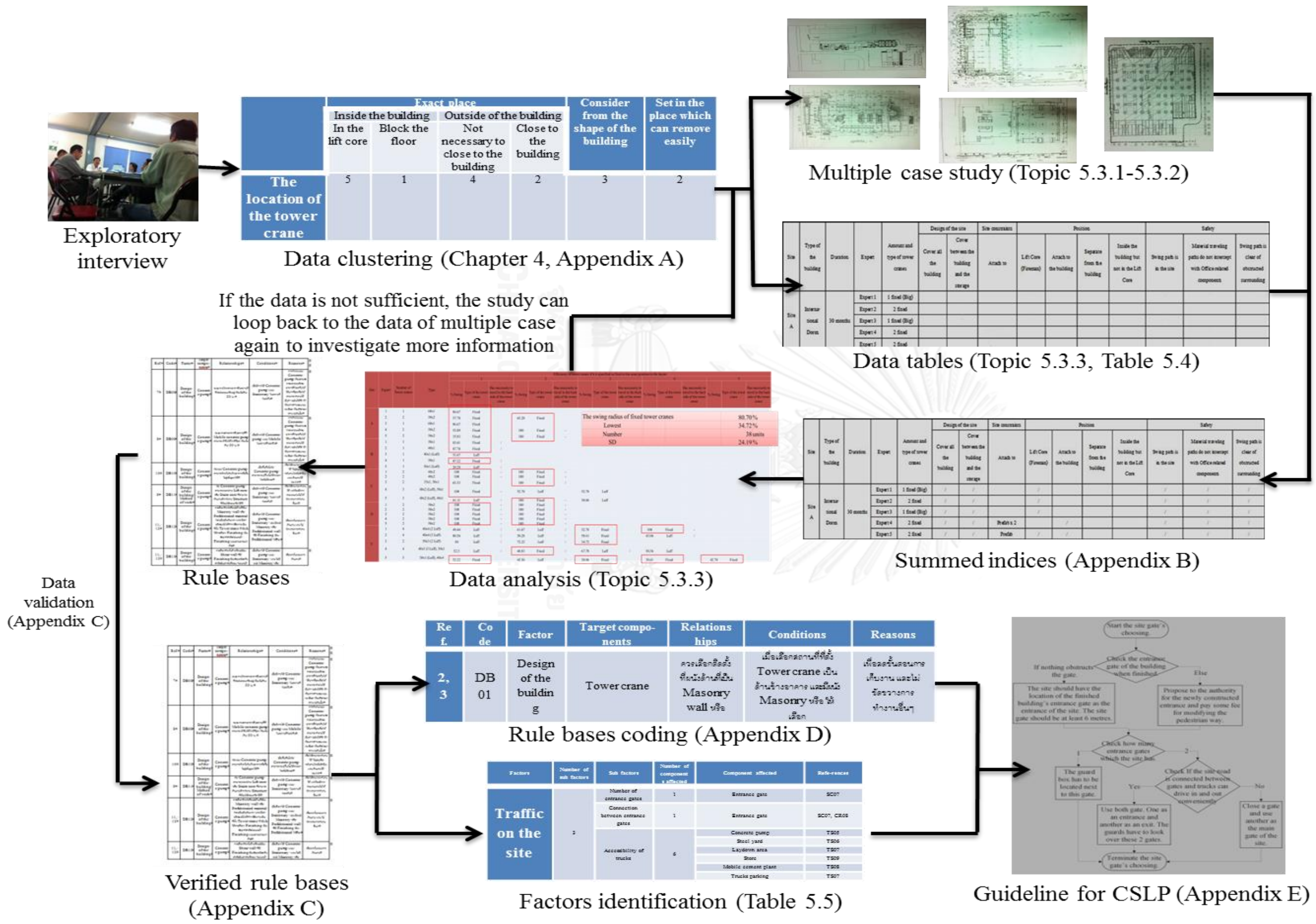


Figure 5.1 Flowchart of the methodology in chapter 5

process. The critical indices are carried on to this phase also and are going to be compared with the output of the multiple case study.

Table 5.1 Data from the exploratory interview about the location of the site office

	In the front of the site	Places where they don’t interfere with other works	Engineers can come to check the work conveniently	Engineers can see all around	Move into the building when the building is ready
Frequency	7	3	2	2	2

5.3 Multiple case study

Multiple case study is conducted to obtain the in-depth information of CSLP. It is separated into three steps which are (1) cases selection, (2) planning of experts, and (3) data processing and analysis.

5.3.1 Case selection

Cases selection plays a vital role for the reliability and validity of the data. Cases have to be selected carefully in order to gain the information which represent the work procedure of the real practice,. Five construction sites are selected as the case studies. Table 5.2 shows the properties of each case. These construction sites have their own unique properties which can produce the similarities and differences between cases. The experts have to manage their CSLP based on their experience and knowledge.

5.3.1.1 Case A

Case A is a construction site which can be rarely encountered in the metropolitan area due to its gigantic free space. The constructing building is an international dormitory which has twenty-two floors. It is located in the alley near downtown district that causes some traffic jam in the daytime. The road in front of the site is 4-lane road with two driving directions. There is one entrance at the centre of the front of the site. The building consists of seven lift cores which one of them is specified as a fireman lift core. The exterior wall is finished by glass, plastering, and prefabricated material. There is a car parking behind the wall at the back of the construction site. There are no structures next to the construction site

Table 5.2 Properties of cases selected in the multiple case study process

	Case A	Case B	Case C	Case D	Case E
Types	International Office	Multi-purpose Building	Office and shopping mall	Domestic Dorm	Shopping Mall
Duration (months)	32	30	32	30	24
Heights (Floors)	22	11	44	17	7
Area of sites (Sq.M.)	10,110	3,328	8,446	3,987	13,165
Area per floor (Sq.M.)	3,234	1,583	6,240	1,620	11,102
Free space (Sq.M.)	6,876	1,745	2,206	2,367	2,063
%Free space	68%	52%	26%	59%	16%
Symmetric shape	No	No	No	Yes	No
Property of walls	Masonry	Masonry	Precast and shear wall	Masonry	Precast
Traffic condition	Clear	Heavy	Heavy	Clear	Heavy
Number of entrance gates	1	2	2	1	1
Permission to park outside	No	Yes	No	Yes	No
Trucks accessibility on the site	Enable	Enable	Enable	Disable	Disable
Nearby environment	Clear	Has pedes-trians	Has pedes-trians and vehicles	Has pedes-trians	Has pedes-trians

5.3.1.2 Case B

It is a construction of a multipurpose building in the university campus. There is some free space which lets the experts be able to plan for their components on the site. The building is symmetrical with eleven floors. There are two lift cores and one stair core at each side. The construction site has two entrances which connect to the 6-lane road with two driving directions. The road usually does not have traffic jam all the day and the traffic regulation allows the cars parking if it is not within rush hours. The other sides are connected with the university's roads. However, there is a huge

22-floor building next to the construction site which might cause some effect on the construction site layout.

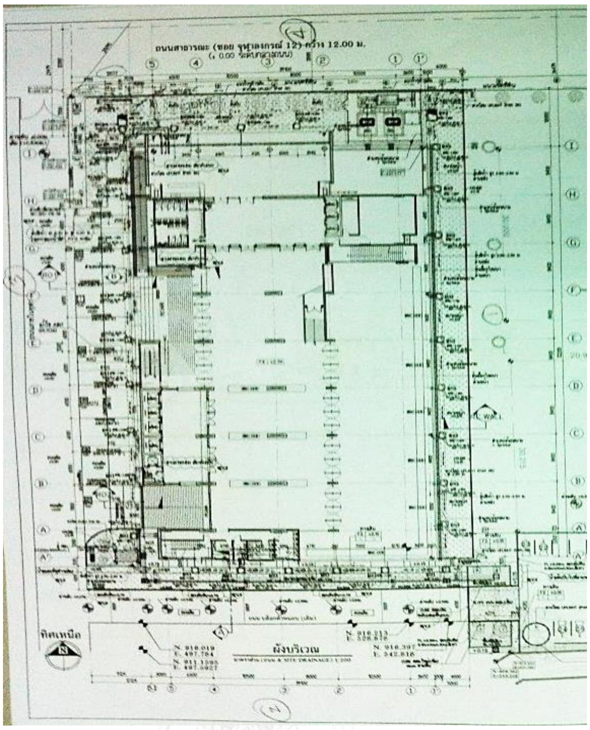


Figure 5.2 The ground floor plan of case A

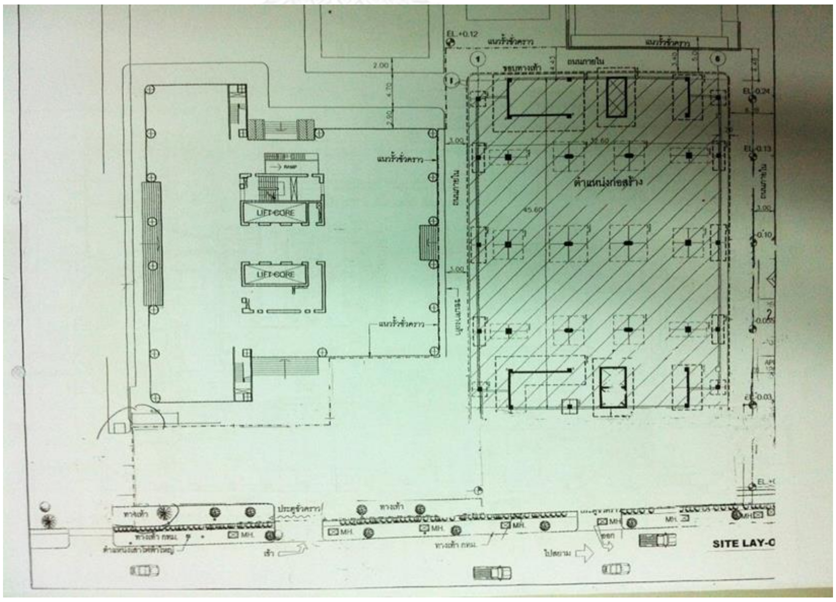


Figure 5.3 Ground floor plan of case B

5.3.1.3 Case C

Case C is a construction of a high-rise office with shopping mall building project. It has a 44-floor tower with a 10-floor podium. It is located at the cramped business district which affected the construction site to have limited free space. The site surrounded with crowded roads, the canal at the back of the site, and a nearby building which owned by the same owner of this construction building. The owner clarifies that the contractor can use the building nearby for free because it is going to be demolished in the second phase of the project. The entrance connected to the main road which has severe traffic jam in the daytime. There are many lift cores separated by the zones where the lifts will deliver the people to; low zone, medium zone, and high zone. The site has two entrances with a road connected between these two gates when the construction is finished.

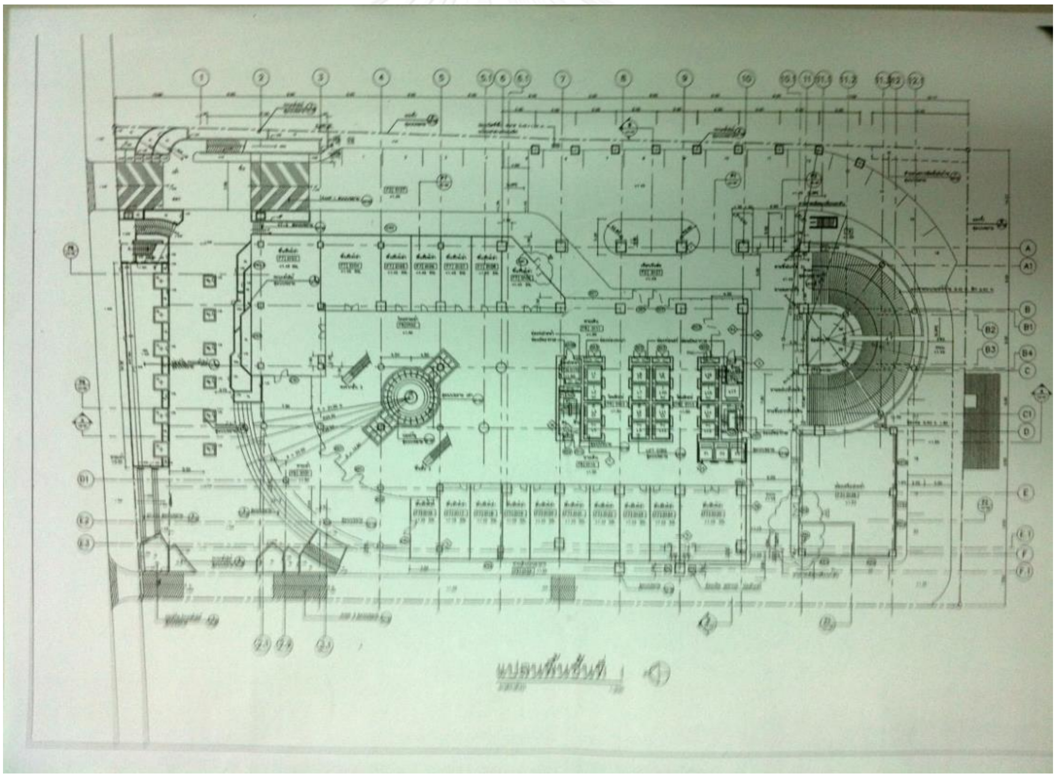


Figure 5.4 Ground floor plan of case C

5.3.1.4 Case D

The building in case D is a long rectangular shape with symmetry. The seventeen-storey structure will be used as a dormitory. Many pedestrians can be observed since there are also dormitories nearby. The site does not connect to the main road directly but there is a personal road that unites the construction site with the main road. This personal road is owned by the owner of the construction site. The main road has 4 lanes which is usually crowded. There are two lift cores at each side. Behind the constructing building, there is a man-built canal. There is a small cafeteria which can be seen from the site layout. The entrance is located at the exactly centre of the building. Finally, the owner specifies that the staff on the site must have workspace at least nine square metres per person.

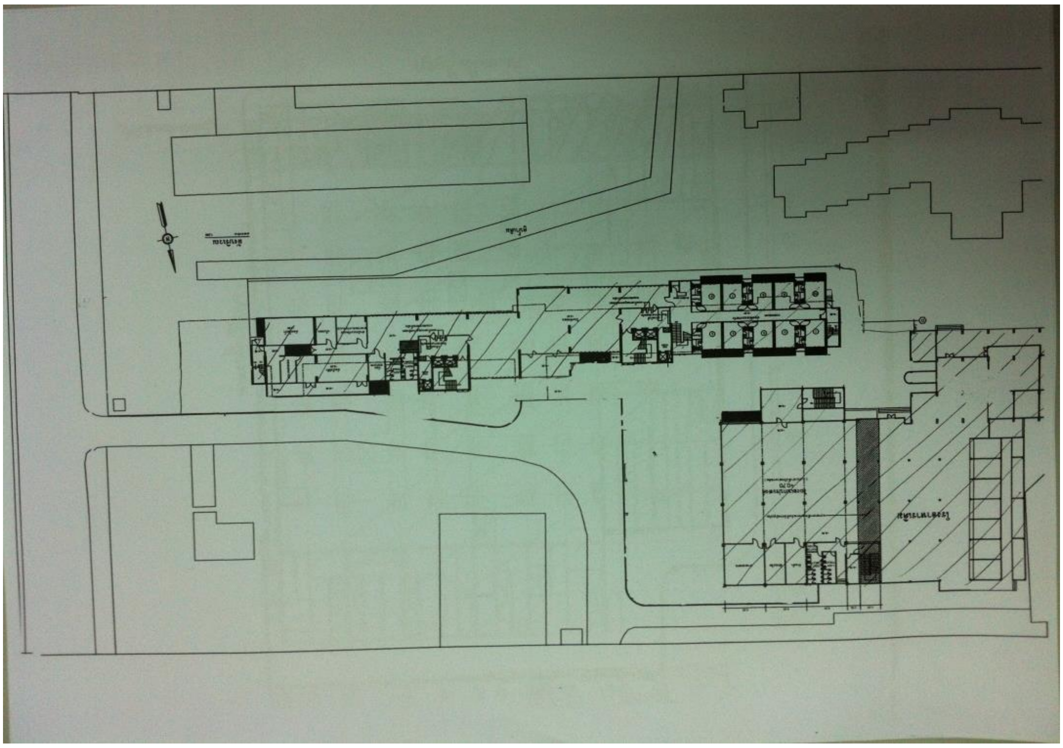


Figure 5.5 Ground floor plan of case D

5.3.1.5 Case E

Case E is located at the centre of the downtown district. The main road, which has 5-lanes and experiences traffic jams, is connected to an entrance gate in front of the construction site. At the back of the side has a small road which is an alley in the shopping district owned by the owner of the construction project. Both sides of the building is surrounded by the department store and commercial buildings. The constructing building has 7 floors. Most of the exterior walls are finished with prefabricated material. The duration is shorter than other cases, only twenty-four months. There is only small amount of the free space but the workspace is enormous compare to the area of the site space.

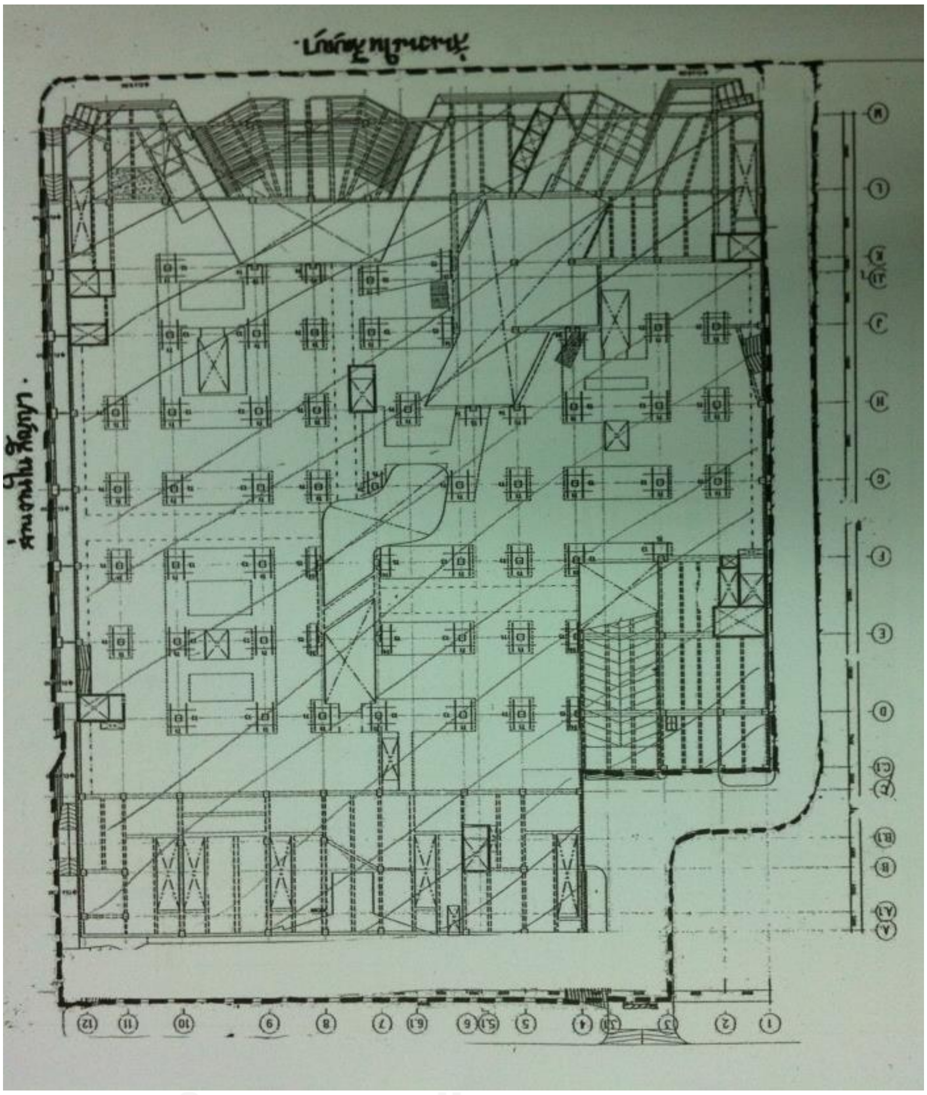


Figure 5.6 Ground floor plan of case E

5.3.2 Planning of experts

The multiple case study is based on face-to-face interviews. Five experts from the exploratory interview participate in this round . The list of all participated expert are shown in Table 5.3. Each expert is proposed with five cases as presented in the previous section. After the experts finish their planning, they clarify the reason why they justify their decision makings for the better understanding and preventing the misinterpretation in data processing. The components, which appear in the layouts from experts, are carried on to the next step of the study.

Table 5.3 List of all participated experts in the multiple case study

Expert	Type of Organization	Education	Position	Experience with the high-rise building CSLP (Years)
A	Contractor	Master Degree	Project Manager	10
B	Consultant	Bachelor Degree	Project Manager	15
C	Contractor	Bachelor Degree	Project Manager	45
D	Contractor	Bachelor Degree	Project Manager Assistance	10
E	Consultant	Bachelor Degree	Project Manager	24

5.3.3 Data processing and analysis

After the experts manage their CSLP for every site, all of the cases are processed by tabular method to find the similarities and differences between each case. The example of data tables is shown in Table 5.4. The data processing of this study bases mainly on variables which are presented in cases. Each variable has its own table to classify the decision that the experts made. The criteria which separate the decisions come from, but not limit to, answers of the exploratory interview after clustering as shown in chapter 5.2. A tick is given to the cell which represents the decision of experts in each case. These tables are called “Summed indices” when the data processing is finished. The similarities and differences of each layout are compared between each other to obtain the findings. The output of this process is the rule bases of CSLP. These rule bases are brought back to the experts who did the multiple case study to check whether the translation is correct and gains the acceptance.

The example of the analysis is shown in Table 5.5 to Table 5.7 and Figure 5.7 about the coverage of tower cranes on each site. All of tower cranes on each layout are drawn their coverages based on their radiuses. Coverages are modified to suit the real practice by subtracting the part which the interested tower crane cannot pass due to the obstruction. For example, the mast of another taller tower cranes and the high building nearby. The swing of the coverage left from the subtracting is measured and written down into the data table. These swings based on the basis of fixed jib tower cranes although the interested tower crane is a luffing jib one in order to analyse the fact behind the decision making. The type of the tower crane and necessity to swing to the unavailable location due to the obstruction are also noted for the more in-depth analysis.

It can be seen from Table 5.5 that the fixed jib tower crane on every layout can make a rotation more than 34% of its full potential with the average of 80%. On the other hand, the luffing jib tower crane can make smaller rotation with minimum of 20% and the average of around 50%., as shown in Table 5.6**.** No less than 20% of the rotation are made from all of tower cranes on 25 layouts. These results lead to the interpretation of 3 rule bases in the rectangular shape on Table 5.7. The data based on the number, such as sizes, and numbers of variables are also investigated. The graph can be plotted by comparing all of numbers from the interested variable equate to some other variables. Figure 5.7 shows the graph plotted between the percentages of free space compared to the percentages of average sizes of steel yards equate to their area sizes. The formula of the graph is rewritten to facilitate the usage.

5.4 Data validation

The rule bases are rearranged into a questionnaire of 5-score Likert's scale to verify the agreement of the expert panel. The score of five means the expert totally agrees with the statement, while four means the expert only agrees with the knowledge. The experts can give the score of three which means they are not sure with the interested statement. On the other hand, the score of two means the expert disagrees. Lastly, the score of one means the expert totally disagrees with the intrigued fact. All of the suggestions are noted for modification of knowledge rule bases. The median is utilized to find the averages of each rule bases. The rule bases which gain the score lower than four (Agree) are eliminated from the final knowledge rule bases of the study. Moreover, the rule bases which have the score of four are modified by the suggestion of the expert panel to gain more validity. Each final knowledge rule bases are extracted to form a sub factor affected the decision. All of sub factors are categorized by factors they are belonged to. Factors, sub factors, conditions, components affected, effects are rearranged into the detailed tabular form in the Appendix C.

Table 5.4 Example of the data table before the data processing

Site	Type of the building	Duration	Expert	Amount and type of tower cranes	Design of the site		Site constraints	Position				Safety		
					Cover all the building	Cover between the building and the storage	Attach to	Lift Core (Fireman)	Attach to the building	Separate from the building	Inside the building but not in the Lift Core	Swing path is in the site	Material traveling paths do not intercept with Office related components	Swing path is clear of obstructed surrounding
Site A	Interna-tional Dorm	30 months	Expert 1	1 fixed (Big)										
			Expert 2	2 fixed										
			Expert 3	1 fixed (Big)										
			Expert 4	2 fixed										
			Expert 5	2 fixed										
Site B	Multi-purpose Build-ing	32 Months	Expert 1	1 fixed										
			Expert 2	1 fixed										
			Expert 3	1 Articulated										
			Expert 4	1 fixed										
			Expert 5	1 fixed										
Site C	Office and Shop-ping Mall	30 Months	Expert 1	2 fixed										
			Expert 2	2 fixed										
			Expert 3	2 fixed										
			Expert 4	3 fixed										
			Expert 5	3 fixed										
Site D	Dorm	32 Months	Expert 1	2 fixed										
			Expert 2	2 fixed										
			Expert 3	2 fixed										
			Expert 4	2 fixed										
			Expert 5	2 fixed										
Site E	Shop-ping Mall	24 Months	Expert 1	3 fixed 1 Arti										
			Expert 2	3 fixed 1 Arti										
			Expert 3	2 fixed 1 Arti										
			Expert 4	3 fixed 1 Arti										
			Expert 5	4 fixed 1 Arti										

Table 5.5 Analysis for the coverages of fixed jib tower cranes from the multiple case study

Site	Expert	Number of Tower cranes	Type	Efficiency of tower cranes if it is specified as fixed at the same position in the layout														
				1			2			3			4			5		
				% Swing	Type of the tower crane	Has neccessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has neccessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has neccessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has neccessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has neccessity to travel to the back side of the tower crane
A	1	1	60x1	86.67	Fixed													
	2	2	50x2	57.78	Fixed		65.28	Fixed										
	3	1	60x1	86.67	Fixed													
	4	2	50x2	53.89	Fixed		100	Fixed	-									
	5	2	50x2	35.83	Fixed		100	Fixed	-									
B	1	1	50x1	83.61	Fixed	/												
	2	1	40x1	87.78	Fixed	/												
	3	1	40x1 (Luff)	51.67	Luff													
	4	1	50x1	87.22	Fixed	/												
	5	1	50x1 (Luff)	20.28	Luff	/												
C	1	2	40x2	100	Fixed	-	100	Fixed	-									
	2	2	40x2	100	Fixed	-	100	Fixed	-									
	3	2	35x1, 50x1	63.33	Fixed		100	Fixed	/									
	4	3	40x2 (Luff), 50x1	100	Fixed	-	52.78	Luff		52.78	Luff							
	5	3	40x2 (Luff), 40x1	61.11	Luff	/	100	Fixed	-	58.06	Luff							
D	1	2	50x2	100	Fixed	-	100	Fixed	-									
	2	2	50x2	100	Fixed	-	100	Fixed	-									
	3	2	50x2	100	Fixed	-	100	Fixed	-									
	4	2	50x2	100	Fixed	-	100	Fixed	-									
	5	2	50x2	100	Fixed	-	100	Fixed	-									
E	1	4	40x4 (2 Luff)	49.44	Luff	/	61.67	Luff	/	52.78	Fixed		100	Fixed	-			
	2	4	40x4 (3 Luff)	80.56	Luff	/	50.28	Luff	/	58.61	Fixed		43.06	Luff	/			
	3	2	50x3 (2 Luff)	50	Luff	/	72.22	Luff	/	34.72	Fixed							
	4	4	40x3 (3 Luff), 50x1	52.5	Luff	/	40.83	Fixed	/	67.78	Luff	/	50.56	Luff				
	5	5	30x1 (Luff), 40x4	52.22	Fixed		45.56	Luff	/	38.06	Fixed		38.61	Fixed		42.78	Fixed	

The swing radius of fixed tower cranes			80.70	%
Lowest			34.72	%
Number			38	units
SD			24.19	%

Table 5.6 Analysis for the coverage of luffing jib tower cranes from the multiple case study

Site	Expert	Number of Tower cranes	Type	Efficiency of tower cranes if it is specified as fixed at the same position in the layout														
				1			2			3			4			5		
				% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane
A	1	1	60x1	86.67	Fixed													
	2	2	50x2	57.78	Fixed		65.28	Fixed										
	3	1	60x1	86.67	Fixed													
	4	2	50x2	53.89	Fixed		100	Fixed	-									
	5	2	50x2	35.83	Fixed		100	Fixed	-									
B	1	1	50x1	83.61	Fixed	/												
	2	1	40x1	87.78	Fixed	/												
	3	1	40x1 (Luff)	51.67	Luff													
	4	1	50x1	87.22	Fixed	/												
	5	1	50x1 (Luff)	20.28	Luff	/												
C	1	2	40x2	100	Fixed	-	100	Fixed	-									
	2	2	40x2	100	Fixed	-	100	Fixed	-									
	3	2	35x1, 50x1	63.33	Fixed		100	Fixed	/									
	4	3	40x2 (Luff), 50x1	100	Fixed	-	52.78	Luff		52.78	Luff							
	5	3	40x2 (Luff), 40x1	61.11	Luff	/	100	Fixed	-	58.06	Luff							
D	1	2	50x2	100	Fixed	-	100	Fixed	-									
	2	2	50x2	100	Fixed	-	100	Fixed	-									
	3	2	50x2	100	Fixed	-	100	Fixed	-									
	4	2	50x2	100	Fixed	-	100	Fixed	-									
	5	2	50x2	100	Fixed	-	100	Fixed	-									
E	1	4	40x4 (2 Luff)	49.44	Luff	/	61.67	Luff	/	52.78	Fixed		100	Fixed	-			
	2	4	40x4 (3 Luff)	80.56	Luff	/	50.28	Luff	/	58.61	Fixed		43.06	Luff	/			
	3	2	50x3 (2 Luff)	50	Luff	/	72.22	Luff	/	34.72	Fixed							
	4	4	40x3 (3 Luff), 50x1	52.5	Luff	/	40.83	Fixed	/	67.78	Luff	/	50.56	Luff				
	5	5	30x1 (Luff), 40x4	52.22	Fixed		45.56	Luff	/	38.06	Fixed		38.61	Fixed		42.78	Fixed	

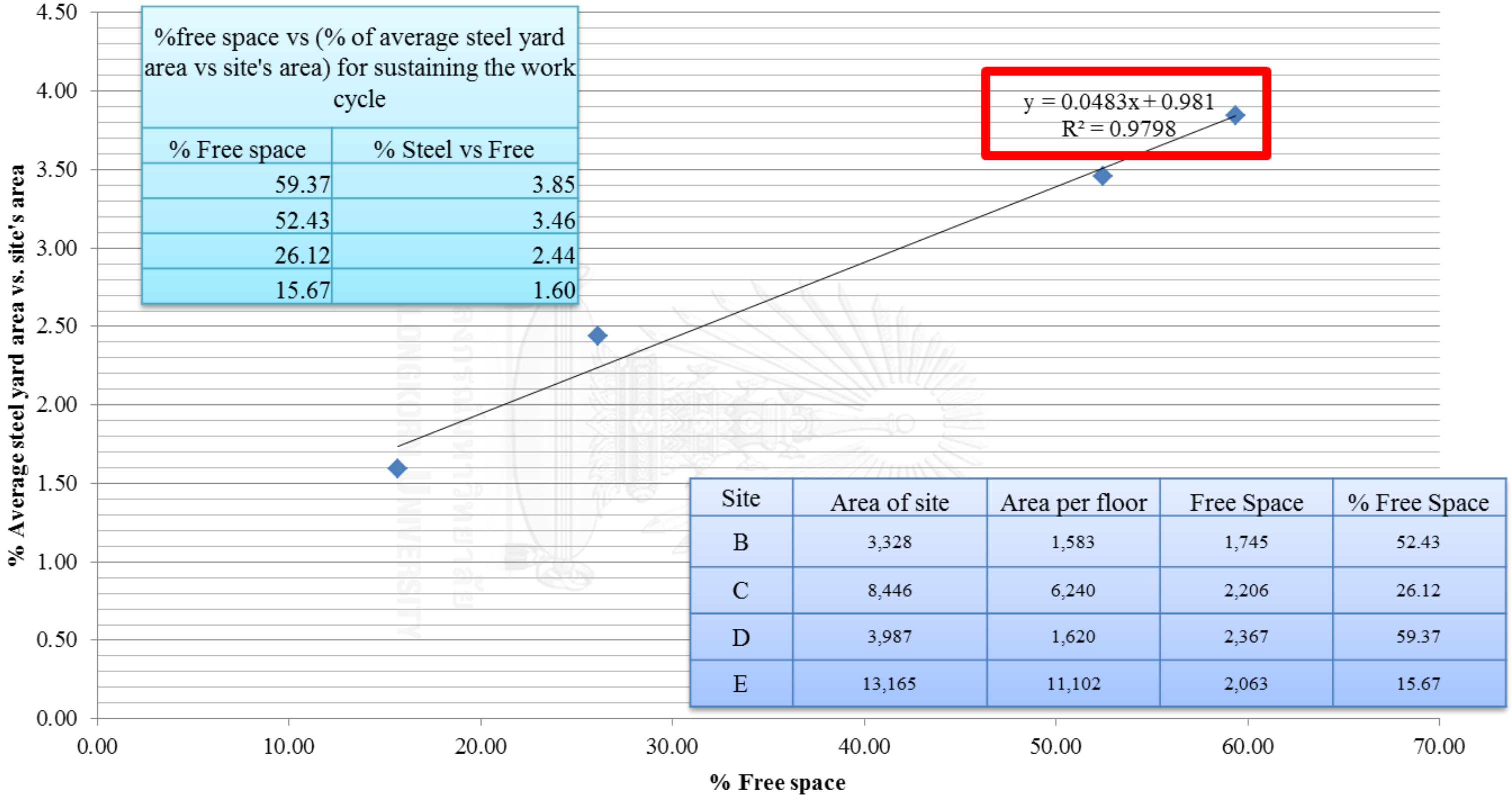
The swing radius of fixed tower cranes			80.70	%
Lowest			34.72	%
Number			38	units
SD			24.19	%

The swing radius of luffing tower cranes			54.13	%
Lowest			20.28	%
Number			17	units
SD			25.86	%

Table 5.7 Rule bases from the interpretation of summed indices

Dominances	Target components	Relationships	Conditions	Reasons
Equipment constraints	Tower crane	Tower crane ควรเลือกติดที่ภายใน Core ของอาคารก่อน จากนั้นจึงเป็นติดตั้งข้างอาคาร และเจาะพื้น ตามลำดับ		เพื่อให้เกิดความคุ้มค่าในการปฏิบัติงาน
		Tower crane ควรเป็นแบบ Fixed	เมื่อสามารถหมุนได้มากกว่า 80% ของระยะการหมุน ณ ตำแหน่งนั้น หรืออย่างน้อยไม่น้อยกว่า 50%	เพื่อให้เกิดความคุ้มค่าในการปฏิบัติงาน
		Tower crane ควรเป็นแบบ Luffing	เมื่อสามารถหมุนได้มากกว่า 50% ของระยะการหมุน ณ ตำแหน่งนั้น หรืออย่างน้อยไม่น้อยกว่า 20%	เพื่อให้เกิดความคุ้มค่าในการปฏิบัติงาน
		Tower crane แต่ละตำแหน่ง ต้องหมุนได้ไม่ต่ำกว่า 20% ของระยะการหมุน ณ ตำแหน่งนั้น		เพื่อให้เกิดความคุ้มค่าในการปฏิบัติงาน
		Tower crane ต้องอยู่ห่างจากตัวอาคารไม่น้อยกว่า 2 เมตรและไม่เกิน 6 เมตร	เมื่อใช้วิธีการติดตั้ง Tower crane แบบติดตั้งข้างอาคาร	เพื่อให้สามารถปฏิบัติงานได้
	Concrete pump	ไม่ควรมีจุดหักแนวราบของท่อคอนกรีตมากกว่า 1 ครั้ง	เมื่อ Concrete pump เป็นแบบ Stationary	เพื่อไม่ให้สูญเสียแรงดันของคอนกรีตเกินความจำเป็น

Figure 5.7 Graph and analysis of the size of steel yards



%free space vs (% of average steel yard area vs site's area) for sustaining the work cycle	
% Free space	% Steel vs Free
59.37	3.85
52.43	3.46
26.12	2.44
15.67	1.60

Site	Area of site	Area per floor	Free Space	% Free Space
B	3,328	1,583	1,745	52.43
C	8,446	6,240	2,206	26.12
D	3,987	1,620	2,367	59.37
E	13,165	11,102	2,063	15.67

$$Size\ of\ the\ Steel\ yard = \frac{Site\ area + 5(Free\ space)}{100}$$

5.5 Findings

Factors, sub factors, and affected components are gathered and shown in Table 5.8. Factors affecting CSLP can be categorized into 13 groups, which are (1) design of the building, (2) availability of the components, (3) relationships of components, (4) constraints of components, (5) traffic on the site, (6) site constraints, (7) man power, (8) method of work, (9) type of the building, (10) location of the site, (11) free space, (12) duration of the project, and (13) specifications and regulations. These factors are extracted into sub factors which the influenced components are also displayed. Codes inside square blankets are references of rule bases related to corresponding facts. All of codes can be examined in the Appendix D.

5.5.1 Design of the building

The factors from the design of the building mainly affect the equipment on the site, which are tower crane, passenger lifts, and the concrete pump. There are 12 sub factors in this category, which are (1) height of the building, (2) shape of the building, (3) properties of the wall, (4) positions of cores, (5) distance between the passenger lift's position and the furthest point of the building from that location, (6) straight location through the height of the building, (7) amount of the concrete using for the building. (8) area per floor (Building's size), (9) coverage of the building covered by tower cranes, (10) distance between the concrete pump's pipe goes through vertically and the furthest point of the building from that location, (11) distance between the location of the mobile concrete pump parked and the furthest point of the building from that location, and (12) distance between the location of the concrete pump's pipe goes through vertically and the concrete pump's location.

5.5.1.1 Height of the building

The height of the building influences the tower crane usage. The tower which is lower than 30 metres can be supported by the standalone type tower crane [CC04]. While the building is higher than 30 metres, the mast of the tower crane must be braced with the building in order to eliminate the risk of collapsing by the buckling. Therefore, the standalone type tower crane is out of choice for the structure with the height higher than 30 metres. The mobile crane can support the construction if the tower is lower than 50 metres [DB04]. This fact causes the project manager of higher than 50 metres building to pay more attention to the coverage of tower cranes. They have to be able to support the entire building unless the inaccessibly location does not have heavy duty related [DB05], for example, removing the column formwork or transportation of heavy material.

5.5.1.2 Shape of the building

The tower crane and the passenger lift are affected by the shape of the building. The project containing building with symmetrical shape can be considered to have the tower crane and the passenger lift at symmetrical locations also [DB06]. For the structure which is a long rectangular shape, the engineer might locate tower cranes and passenger lifts at each side of the building [DB16]. On the other hand, the tower crane and the passenger lift might be located at the centre of the building, if the duration for the decoration of the wall is shorter than a month [MW03 and MW04].

5.5.1.1 Properties of the wall

The finishing type of the wall can alter the construction site layout. Passenger lifts, tower cranes, and stationary concrete pumps should be placed at the masonry wall before the shear wall due to the convenience of its redecorating method [DB01, DB02, DB12, DB13, DB18, and DB19]. The prefabrication material can be utilized to decorate the building by installing it with the structure's wall. It can decrease the wall finishing duration by concealing the damage from the equipment uninstallation. Therefore, there is no need to redecorate the defect on the hidden wall. However, the glass wall should be avoided due to its fragile nature [DB03, DB14, and DB20].

5.5.1.2 Positions of cores

The tower crane can be installed into the core of the building [CC01 and CC05], for instance, the stairs core and the lift core. It has many benefits from this installation. First, it can save cost from the foundation construction or modification of the tower crane. Second, it can reduce the amount of mast usage of the tower crane. Third, the tower crane in the core can cover building effectively due to the nature of cores which are usually located at the centre of the structure. However, there are huge disadvantages from this installation type. It has to be removed at least 6 months

Table 5.8 Factors, sub factors, and the affected components

Factors	Number of sub factors	Sub factors	Number of components affected	Components affected	References
Design of the building	12	Height of the building	1	Tower crane	DB04, DB05, CC04
		Shape of the building	2	Tower crane	DB06, MW03, MW04
				Passenger lift	DB16, MW03, MW04
		Properties of the wall	3	Passenger lift	DB18, DB19, DB20
				Tower crane	DB01, DB02, DB03
				Concrete pump	DB12, DB13, DB14
		Positions of cores	1	Tower crane	DB11, CC01, CC05
		Distance between the passenger lift's position and the furthest point of the building from that location	1	Passenger lift	DB21
		Straight location through the height of the building	3	Passenger lift	DB22
				Tower crane	DB07
				Concrete pump	DB10
		Amount of the concrete using for the building	1	Mobile cement plant	DB23
		Area per floor (Size of the Building)	1	Passenger lift	DB16, DB17
		Coverage of the building covered by tower cranes	1	Tower crane	DB04, DB05
		Distance between the concrete pump's pipe goes through vertically and the furthest point of the building from that location	1	Concrete pump	DB08
		Distance between the location of the mobile concrete pump parked and the furthest point of the building from that location	1	Concrete pump	DB09
		Distance between the location of the concrete pump's pipe goes through vertically and the concrete pump's location	1	Concrete pump	DB15

Table 5.8(Continued) Factors, sub factors, and the affected components

Factors	Number of sub factors	Sub factors	Number of components affected	Component affected	References
Availabilities of components	-	-	5	Passenger lift	CA01
				Tower crane	CA02
				Concrete pump	CA05
				Site office	CA03
				Store	CA04
Relationships between components	7	Usage of the Mobile cement plant	1	Site office	CR01, DB23, LS05, LS06, FS04, TS08, SR04, SR05, SR06, SR07
		Type of the site office	1	Toilet	CC11, CC12, CC13, CC14, MP01, MP02
		Position of passenger lifts	1	Toilet	CR04
		Coverage of tower cranes over other components	3	Steel yard	CR05
				Toilet	CR07
				Laydown area	CR06
		Material inside the store	1	Store	CR09
		Number of tower cranes	1	Tower crane	MW01, MW02
		Distance between the site office and the staff's toilet	1	Toilet	CR03
Constraints of components	11	Rotation of the tower crane	1	Tower crane	CC06, CC07, CC08
		Distance from the building to the tower crane	1	Tower crane	CC09
		Number of the concrete pump	1	Concrete pump	CC17, TB03, DP02
		Bending of the concrete pump's pipe	1	Concrete pump	CC18
		Radius of the tower crane	1	Tower crane	CC10
		Size of toilets	1	Toilet	CC15, SR02, CR02
		Size of the store	1	Store	CC16
		Size of the steel yard	1	Steel yard	FS03
		Properties of the tower crane	1	Tower crane	CC01, CC02, CC03
		Type of the concrete pump	1	Concrete pump	TS01, TS02, TS03, TS04, TS05
		Number of the passenger lift	1	Passenger lift	CC19

Table 5.8(Continued) Factors, sub factors, and the affected components

Factors	Number of sub factors	Sub factors	Number of components affected	Component affected	Refe-rences
Traffic on the site	3	Number of entrance gates	1	Entrance gate	SC07
		Connection between entrance gates	1	Entrance gate	SC07, CR08
		Accessibility of trucks	6	Concrete pump	TS05
				Steel yard	TS06
				Laydown area	TS07
				Store	TS09
				Mobile cement plant	TS08
				Trucks parking	TS07
Site constraints	5	Size of the construction site	1	Laydown area	SC01
		Position of the entrance gate	4	Site office	SC03
				Laydown area	CR10
				Mobile cement plant	SR04, SR05
				Entrance gate	SC06
		Walk path on the site	2	Protection	TB02
				Passenger lift	SC08
		Place where can be the final place to be decorated	1	Site office	SC04
		Material path	2	Site office	SC02
				Toilet	SC05
Man power	2	Number of labours	2	Passenger lift	DB17
				Toilet	SR02
		Number of staff	1	Site office	MP01, MP02
Method of work	5	Movement of components	2	Store	FS06, MW06
				Site office	FS07, FS8
		Preparation of the steel	1	Steel yard	FS03
		Passenger lift's duty	1	Passenger lift	MW05
		Usage of mobile cranes	1	Tower crane	DB04
		Duration for the redecorating of walls	2	Tower crane	MW03
				Passenger lift	MW04
Type of the building	1	High-rise building	4	Tower crane	TB04
				Protection	TB02
				Passenger lift	TB01
				Concrete pump	TB03

Table 5.8(Continued) Factors, sub factors, and the affected components

Factors	Number of sub factors	Sub factors	Number of components affected	Component affected	Refe-rences
Location of the site	5	Pedestrians or cars passing near the site	1	Protection	LS01
		Permission to park outside of the site	2	Trucks parking	LS02, LS03
				Concrete pump	LS02, LS03
		Man holes around the site	1	Toilet	LS04
		Traffic condition around the site	1	Mobile cement plant	LS05
		Nearby environment	3	Mobile cement plant	LS06
				Toilet	LS07
				Tower crane	LS08, LS09
Free space	3	Amount of the free space	4	Steel yard	FS01, FS02, FS03
				Mobile cement plant	FS04
				Store	FS06
				Site office	FS07
		Corners or niches on the site	1	Toilet	FS05
		Availability of truck's parking	1	Trucks parking	FS09
Duration of the project	-	-	5	Passenger lift	DP03
				Tower crane	DP01
				Concrete pump	DP02
				Site office	CC11, CC12, CC13
				Store	CC13
Specifica-tions and regulations	4	Specifications from the owner	2	Mobile cement plant	SR06
				Site office	SR01, MP01, MP02
		Regulations	3	Mobile cement plant	LS06
				Protection	SR08
				Toilet	LS07
		Right of the land nearby	1	Tower crane	SR03, LS01
		Specification from the mobile cement plant's supplier	1	Mobile cement plant	SR04, SR05, SR07

before the construction finishes because it obstructs the construction of the stairs or the lift. Therefore, if there is only one tower crane, it means the construction site will have no tower cranes to support the work for 6 months. Furthermore, the derrick crane must be installed in order to remove the tower crane which is also an expense for the engineer. The stationary concrete pump is also affected by the positions of cores. The pipe of the concrete pump can go through the lift core or stairs core, if those cores can be finished later than the concrete pouring work [DB11]. The reason is the pipe can obstruct the finishing of these cores and the delay can be occurred unless a well planning is made beforehand.

5.5.1.3 Distance between the passenger lift's position and the furthest point of the building from that location

The passenger lift is an equipment to transport people to the destined floor conveniently. For this reason, the walking distance of the labour should be limited to 100 metres from the passenger lift to the work space in order to prevent the unnecessary fatigue [DB21].

5.5.1.4 Straight location through the height of the building

The components on the site usually require space on the ground. However, some equipment demand the area on the vertical axis also. These equipment are passenger lifts, tower cranes, and the stationary concrete pumps. The rail of the passenger lift and the mast of the tower crane cannot bend to follow the design of the structure [DB07 and DB22]. In the concrete pump's case, although the pipe of the concrete pump can go along with the structure, it should have no bends. Bends decrease the force used to deliver the concrete which is a loss. Therefore, they have to be located at the position where is straight from the start point to the final destination [DB10].

5.5.1.5 Amount of the concrete using for the building

The engineer can plan for the usage of the mobile cement plant by knowing this factor. The expert panel agrees that the amount of the concrete should exceed 40,000 cu.m., in order to use the mobile cement plant at the worthwhile stage [DB23].

5.5.1.6 Area per floor (Building's size)

The area per floor affects the number of the passenger lift significantly from the multiple case study. The data validation shows that if the answer after dividing the area per floor by the initial number of passenger lifts is lower than 1000 sq.m./unit, the engineer should decrease the number of the passenger lift usage by 1 but not lower than 1. On the other hand, if the value is more than 2,000 sq.m./unit, the engineer should increase the number of the passenger lift by 1 and recalculate again [DB17]. The engineer has to concern for the extra location to be installed another passenger lift's rail if the original number is 2 already. However, if the area per floor exceeds 10,000 sq.m., the position of the passenger lift should be increased to be at least 2 places also [DB16].

5.5.1.7 Coverage of the building covered by tower cranes

Ideally, the tower crane should be able to support the entire building. Anyhow, the tower crane, in fact, is not necessary to cover totally. The evidence is the summed index of the tower crane's coverage from the multiple case study which is shown in Table B21. It presents the average of the building's coverage which is 97%. The expert panel agrees with this statement and suggests the inaccessibly area can be supported by the mobile crane [DB04]. However, there is a restriction that the mobile crane can support the work at the elevation lower than 50 metres only. Therefore, the building which is higher than 50 metres should be entirely covered by the tower crane [DB05].

5.5.1.8 Distance between the concrete pipe goes through vertically and the furthest point of the building from that location

Based on the summed index of the length of concrete pump's pipe (Table B25), it is observed that the distance from the bend of pipe to the furthest point of the building should not exceed 50 metres [DB08]. Nevertheless, this is only an approximate value. The power of the pump, bends, fission, gravity, and length should be considered for the precise calculation.

5.5.1.9 Distance between the location of the mobile concrete pump parked and the furthest point of the building from that location

The concrete pump cannot shoot further than 50 metres [DB09]. Moreover, the expert suggested that the mobile concrete pump shoot be parked at only one place. Consequently, the engineer should specify an exact location for the mobile concrete pump to be able to support every area of the building. Anyway, the precise calculation might be made to find the exact limitation. This rule base is gathered by the analyzing of Table B25

5.5.1.10 Distance between the location of the concrete pipe goes through vertically and the concrete pump's location

From the summed indices of the distance between the building and the concrete pump (Table B25), the expert panel agrees that the stationary concrete pump’s pipe should not be too long before bending up to the vertical axis. The optimal distance is not over 30 metres [DB15] but the precise calculation might be made for more detail.

5.5.2 Constraints of components

This factor relates to the properties and limitations of components on the site. The sub factors are clustered into eleven groups, which are (1) rotation of the tower crane, (2) distance from the building to the tower crane, (3) number of the concrete pump, (4) bending of the concrete pump's pipe, (5) radius of the tower crane, (6) size of toilets, (7) size of the store, (8) size of the steel yard, (9) properties of the tower crane, (10) type of the concrete pump, and (11) number of the passenger lift.

5.5.2.1 Rotation of the tower crane

The rotation of the tower crane reflects the choice of the experts. The Table B22 in the appendix B shows that five from thirty-eight fixed jib tower cranes in the multiple case study can rotate more than 50% of its revolution. On the other hand, all seventeen luffing jib tower cranes can swing more than 20%. From these findings, the principle of choosing jib type of the tower crane is affected by the rotation of the tower crane. If the rotation of the fixed jib tower crane at that position can be made more than 80%, it can be placed at that exact position [CC06]. While, if the revolution does not exceed 50%, the tower crane at that position should be a luffing jib [CC07].

However, if the rotation is lower than 20%, the engineer should consider choosing another place as a tower crane's base [CC08].

5.5.2.2 Distance from the building to the tower crane

This factor affects the tower crane installation. The standalone tower crane with the bracing with the building is called an attached tower crane. However, the standalone type cannot be used with the over 30-metre building. Therefore, the tower crane must be braced and changed to an attached tower crane. The summed indices from Table B23 shows that distances between the building and attached tower cranes are around the range of 2 to 6 metres. The validation confirms that experts agree this distance should not exceed 6 metres so, the bracing can be done conveniently [CC09].

5.5.2.3 Number of the concrete pump

The expert panel agrees that for the high-rise building, there should be at least a concrete pump on the site to support the concrete work [TB03, CC17]. However, it might be possible that the site might require more concrete pumps to sustain the work flow [DP02].

5.5.2.4 Bending of the concrete pump's pipe

The flow of the concrete can be affected by bends of the pipe. From Table B25, it can be seen that not necessary bends of the pipe should be eliminated by changing the location of the stationary concrete pump or direction of the pipe. The maximum number of bends which the experts gain the consensus is not more than one [CC18].

5.5.2.5 Radius of the tower crane

There are various radiuses of tower cranes. From the multiple case study, the common radiuses are between 30 to 50 metres with the interval of 5 metres as shown in Table B24. This attribute affects directly to the coverage of the tower crane which the engineer has to focus later. Moreover, the radius of the tower crane should be considered along with the capacity at each distance of its jib [CC10]. The jib of the tower crane can withstand different amount of weight due to the shear and the moment cause to the structure of the tower crane. Consequently, the engineer should check at the point where the jib of the tower crane has to carry the material whether it is able to transport.

5.5.2.6 Size of toilets

The size of toilets must be checked in order to prevent the illegal design on the site. The overall toilets have to pass the labour legislation. The size of toilets can be calculated by the multiplication of the number of rooms and the size of each room which should be around 1.5 metres to 4 metres [CC15]. For the number of room, it can be acquired by comparing the number of labours with the labour legislation [SR02]. On the other hand, the number of staff's toilet from the data validation reaches the consensus at having at least a room for each gender inside the site office [CR02].

5.5.2.7 Size of the store

The engineer should specify the size of the store before placing on the site. The usual size of the store from the multiple case study is around 65 to 80 sq.m. [CC16]. It is displayed in Table B19.

5.5.2.8 Size of the steel yard

From the multiple case study shown in Figure B1, it can be seen that the size of the free space is a proportion with the free space on the site and the area of the site. The formula can be formed from the graph between the size of the steel yard and the ratio between free space and area of the site. After modification, the area of the steel yard can be calculated by the area of the site pluses five times of the free space divided by one hundred [FS03].

5.5.2.9 Properties of the tower crane

The jib type and installation type should be specified before the placing of the tower crane. This factor affects the coverage of the tower crane over the site and the building. For the jib type, there are two types of jibs. First, the fixed jib is a horizontal lying jib without bends. It can travel only two axes, while, the luffing jib can travel in three axes. It results more flexible but slower rotating. Furthermore, the tower crane can be installed on the construction four types. First, the tower crane can be installed into the lift core or stairs core. It is the most cost effective installation but requires a well-planned scheduling for the work on site [CC01]. Second, it can be attached to the side of the building. It is the most convenient way to install and uninstall the tower crane [CC02]. However, it will cost the modification of the foundation and the purchasing of masts. Third, the tower crane can be placed inside a building by blocking the floor [CC03]. It has major impact with the scheduling due to the redecorating floors. The expense is also a concern if this implementation is selected. Finally, the tower crane can be settled freely without any bracing [CC04]. Anyway, this method can be implemented if the building does not exceed 30 metres.

5.5.2.10 Type of the concrete pump

The concrete pump can be categorized into two types. The first type is the stationary concrete pump. It requires space on the site. It has to be attached with a pipe to deliver the concrete to the destination [TS01]. The latter type is the mobile concrete pump. This kind of pump likes a truck having a stationary concrete pump attached to its back. It can go wherever on the site if it can access [TS02], however, the experts suggest that it should be located at only one place [TS03, TS04] like the stationary concrete pump due to its complex setting before it can operate. The concrete pump needs the supply from the concrete truck to be functional [TS05].

5.5.2.11 Number of the passenger lift

The engineer has to know the number of the passenger lift in order to specify its location. The location in this case is the location of the passenger lift's rail. This rail is used to let the passenger lift travels up and down. It can be separated into two types which are single cage and double cages [CC19]. The single or double is the number of the passenger lift installed with the rail which means that the single cage's rail can carry only a passenger lift. On the other hand, the double cages one can carry two passenger lifts.

5.5.3 Relationships between components

CSLP consists of enormous number of components on the site. It cannot be rejected that the relationships between components is a factor that can influence the layout also. Some components have to be placed with each other, while others might have to be located far away. There are seven sub factors, which are (1) usage of the mobile cement plant, (2) type of the site office, (3) position of passenger lifts, (4) coverage of tower cranes over other components, (5) material inside the store, (6) number of tower cranes, and (7) distance between the site office and the staff's toilet.

5.5.3.1 Usage of the mobile cement plant

The engineer has to specify from many factors whether the mobile cement plant should be utilized [DB23, LS05, LS06, FS04, TS08, SR04, SR05, SR06, and SR07]. However, if it is used, it will affect the construction site layout by altering the position of the site office. The site office has to be moved to other side of the site, far away from the mobile cement plant due to the dust and trucks around the plant [CR01].

5.5.3.2 Type of the site office

The site office has two major types. First, the newly built site office is usually established when the site has many free space and has more than two years of the project's duration [CC12]. Second, the prefabricated site office is often utilized with the site which has less free space and the site office has to be moved into the building to save the outside area [CC11]. The planner can design the size of the laydown area [CC13]. The size of the site office is little influenced by the type of the site office. If the site office is newly built, the size of the site office can be built at any size as the engineer wants. However, if the site office is prefabricated, the actual size of the site office has to be modified from the calculated size to conform to the material [MP01 and MP02]. For example, the usual material for a site office is a steel container. Its size is around 2.5x6 metres so the calculated size should be rounded off to suit the 15 sq.m. of the container. The type of the site office also affects the type of the staff's toilet. If the site office is newly built, the staff's toilet can be constructed inside the site office which is preferable by the experts [CR02]. It can raise the productivity and safety of the staff. However, if the site office is designed to be prefabricated, the staff's toilet has to be located elsewhere but separated from the labour's toilet [CC14].

5.5.3.3 Position of passenger lifts

The toilet is influenced by many factors. One of them is the position of the passenger lifts. The data from the multiple case study in Table B5 show that there are no layouts which the experts located the toilet near the passenger lift. Consequently, it leads to the conclusion that the toilet has to be settled out of the passenger lift's area [CR04].

5.5.3.4 Coverage of tower cranes over other components

Apart from the coverage over the building, the tower crane's coverage has to be considered about other components also. The tower crane has to be able to support the transportation on the site. Thus, the storages on the site, which are the steel yard and the laydown area, have to be accessibly by the tower crane [CR05 and CR06]. The evidence can be seen from the summed indices of the steel yard and the laydown area in Table B2, B7, and B21. On the other hand, the toilet has to be placed outside of the tower crane's coverage [CR07]. If the planner cannot achieve that statement, the toilet at least has to be settled outside of the material path on the site [SC05].

5.5.3.5 Material inside the store

This material inside the store can influence the construction site layout also. From the exploratory interview shown in Table A14, the answers from the experts can be clustered into two major groups. The first group is placing with the site office, while the second group is placing near the constructed building. However, there are no clear and quantitative explanations why the difference occurs. It is found later from the data validation process of the multiple case study that the factor affecting the decision is the material inside of the store [CR09]. The store does not have to be placed near the site office unless it stores the valuable material or equipment. The stock can be justified by the work plan which materials or equipment have to be stored.

5.5.3.6 Number of tower cranes

The number of tower crane can be a condition for the installation type choosing of the tower crane. The expert panel agrees that the first tower crane on the site should be attached to the building due to the convenience of the installation [MW02]. Moreover, having a tower crane attached to the building can assist the uninstallation of other tower cranes, especially the ones inside the building or cores [MW01]. The uninstallation of these tower cranes is complex and difficult because it cannot remove itself.

5.5.3.7 Distance between the site office and the staff's toilet

The staff’s toilet cannot be constructed with the prefabricated site office. Consequently, it has to be located somewhere on the site instead. The expert panel suggested the toilet should not be placed too far from the site office due to the productivity of the working. The distance should not exceed 50 metres which is raised as the optimal length to be placed staff’s toilet [CR03].

5.5.4 Location of the site

The information of the location of the site sometimes cannot be gained from the site plan, for example, it might not be detailed enough to know the position of the man holes, nearby building, and also does not specify the traffic condition around the site. The engineer can gather these missing data by visiting the real construction site before managing CSLP. The five sub factors are categoried as fellows: (1) pedestrians or cars passing near the site, (2) permission to park outside of the site, (3) man holes around the site, (4) traffic condition around the site, and (5) nearby environment.

5.5.4.1 Pedestrians or cars passing near the site

Sometimes, the construction site is located close to roads or pedestrian ways where accidents can occur. The summed indices from Table B15 show that the engineer has to construct safety roofs to prevent the falling objects due to the safety aspect [LS01].

5.5.4.2 Permission to park outside of the site

One of the problems with the construction project nowadays is the lack of free space. The trucks might not be able to access onto the site. Therefore, the transportation cannot go smoothly. The first solution is to consider whether the trucks can park outside of the construction site. If they can park, it would relieve the transportation on the site by letting the tower crane to handle the delivering into the site [LS02]. Concrete trucks may queue outside to pour the concrete. However, if they cannot park, the engineer has to contact the traffic police to get the approval [LS03]. Moreover, considering changing the work plan to pour the concrete or delivering the material in the night when few cars travel by is also a good idea to lighten the traffic condition around the site as can be seen from Table B3.

5.5.4.3 Man holes around the site

Man holes can influence the toilet's location because the toilet has to drain the used water to them. The experts agree that the toilet should be placed near the man holes for the more convenient drainage [LS04]. However, if it is not feasible to place near the man holes, a culvert from toilets to man holes can assist the drainage instead.

5.5.4.4 Traffic condition around the site

This factor directly affects the delivery to the construction site, especially the concrete which requires continuous pouring. The concrete may form layers unless the pouring is uninterrupted. For the construction site which has severe traffic conditions, a mobile cement plant may be feasible to be utilized on the site [LS05]. The concrete trucks can go back and forth from the plant to the building continuously. Therefore, the factor about the traffic condition outside of the site is eliminated.

5.5.4.5 Nearby environment

The construction affects the nearby environment particularly those that are close to residential areas. It might be a source of environmental problems, for example, the dust and the smell. Moreover, there is also risk from falling debris. From these reasons, the components which can cause trouble must be planned for measurements to eliminate most of the risks. The toilet should be located far away from sides near the neighbourhood [LS07]. The mobile cement plant must be considered whether it should be utilized on the site. The dust might go outside of the construction site and cause trouble to the neighbours [LS06]. Finally, the planning for tower cranes must be aware of tall buildings nearby the construction site. It might collide with a building due to carelessness of the operator or the occurrence of natural phenomenon like a storm [LS08 and LS09].

5.5.5 Traffic on the site

The traffic of the site directly affects to the transportation on the site. The components which require the assistance from trucks, such as the concrete pump, the steel yard, and the laydown area have to be mainly planned according to the sub factor of the traffic on the site. The full list of sub factors in this group are (1) number of entrance gates, (2) connection between entrance gates, and (3) accessibility of trucks.

5.5.5.1 Number of entrance gates

The number of entrance gates play vital role for the traffic on the site. It is forced to be a one way direction unless the site has more than one entrance gate. However, if the site has two entrance gates, it does not mean that the engineer has to use both gates. The engineer might close one gate and use another gate only for higher security level on the site [SC07]. The summed indices about this issue are shown in Table B15.

5.5.5.2 Connection between entrance gates

This factor has to be considered when the construction site has more than one entrance gate only. From the multiple case study, both Case B and Case C have two entrance gates. However, all of the experts plan Case B to utilize both gates, while three from five of the experts plan Case C to utilize only a gate. The reason after validation is that trucks can be driven pass between gates of Case B conveniently. On the other hand, the travel of site C is very long and some experts plan to place components which will obstruct the traffic [SC07]. In conclusion, the traffic should not be obstructed and trucks can be driven pass these gates conveniently [CR08].

5.5.5.3 Accessibility of trucks

Accessibility of trucks influences the hugest amount of components on the site. The concrete pump, the steel yard, the laydown area, the store, the mobile cement plant, and the trucks parking are the affected components [TS05, TS06, TS07, and TS08]. These components require trucks to be able to assist or deliver the material to them, except the store which only pick-up accessibility is enough [TS09]. The material path on the site is also affected by the accessibility of trucks. If trucks cannot be driven into the site, there will be more material paths occur between the trucks parking and the storages. However, if some of these storages cannot be accessed, the tower crane can come in to support the work instead [LS02 and LS03]. Consequently, the tower crane should gain accessibility to the delivery spot unless trucks can reach their destinations themselves.

5.5.6 Method of work

The construction site layout might involve mainly to the design of the building and the plan of the site. However, the work plan can affect and be influenced by the construction site layout also. The sub factors in this group are (1) movement of components, (2) preparation of the steel, (3) passenger lift's duty, (4) usage of mobile cranes, and (5) duration for the redecorating of walls.

5.5.6.1 Movement of components

The answers from the exploratory interview, site investigation and the multiple case study have consensus about the store and the site office. They are the only two components which are able to be moved on the site as can be seen in Table A2 and B10. The movement is occurred by the major cause of the free space shortage [FS06 and FS07]. The evidence is the movement which happens only with the construction site with low free space in the summed indices in Table B10 and the consensus from the expert panel. Moreover, these components are able to form a 2-floor component which the site office can be located above the store or another site office, if the planner does not want to move these components inside the building [FS08].

5.5.6.2 Preparation of the steel

It is a suggestion from the expert in the data validation process that the preparation of the steel is also a factor to be concerned. The condition is justified by the size of the steel yard calculated from the proposed formula in Figure 5.7. If the answer is lower than 100 sq.m., the steel should be prepared from outside of the site and delivered to the storage when it is needed. [FS03]

5.5.6.3 Passenger lift's duty

Although the main propose of the passenger lift is carrying humans to the destined floors, it sometimes has to assist the transportation also. A suggestion from the expert panel that if the passenger lift does not have to start operating at the ground floor unless it has to transport material [MW05]. The reason behind is to relieve the crowded areas on ground floor. It can separate between the labours who has to work on the ground floor, where usually has many work and confused human traffic, with the labours who are waiting for the transportation to other floors.

5.5.6.4 Usage of mobile cranes

The mobile crane can assist the work on the site like tower cranes. Though, it costs some expense for hiring. The engineer has to plan carefully why and when to use the mobile crane to assist the work. The summed indices in Table B21 from the multiple case study shows that the mobile cranes can assist the area where tower cranes do not cover. There is a constraint that usually mobile cranes cannot assist the work which is too high. The expert panel agrees that it would be around 50 metres [DB04].

5.5.6.5 Duration for the redecorating of walls

The last phase of the construction project is to refurbish all of defects before delivering the project to the owner. The amount of this duration can be justified by the work plan of the project. The longer the duration is, the less probability that the repairing can be one in time is higher. However, if the duration is short, it is advisory that the engineer should keep refurbishing works at the minimum. Therefore, the equipment, which have to be installed with the wall, like tower cranes [MW03] and passenger lifts [MW04] are forced to be retained at the minimum number. The passenger lift might be installed only at a place with two cages type instead of installing two places with single cage type each. Based on the survey, the optimal amount of time that the redecorating can be finished in time is one month. If there is a month for the redecorating of walls from the schedule, the planner can install tower cranes and passenger lifts at walls more.

5.5.7 Site constraints

The site constraint focuses on the limitation on the site, for example, the size and the routes of the material and human on the site. It can be separated into four categories, which are (1) size of the construction site, (2) position of the entrance gate, (3) walk path on the site, and (4) material path.

5.5.7.1 Size of the construction site

The size of the construction site can be known from the plan of the construction site. It can be utilized as the input for the proposed formula to calculate for the laydown area's size [SC01]. The size of the construction site can further be used to calculate for the amount of the free space on the site.

5.5.7.2 Position of the entrance gate

Knowing the position of the entrance gate leads the engineer to acknowledge which side of the site is considered to be the front. The entrance gate has to be specified first where it should be located. Usually, if nothing obstructs the entrance of the building when finished, the entrance gate of the site will be located at the same place with the entrance gate of the building [SC06]. However, if the engineer would like to change the location from this default, the engineer has to contact the authorities for the approval, which costs time and money. The site office, the mobile cement plant, and the laydown area are all affected by the position of the entrance gate. They are likely to be placed at the front of the construction site [SC03, SR04, SR05, and CR10].

5.5.7.3 Walk path on the site

The construction environment is a dangerous work in itself. However, CSLP can prevent the accident when the construction is operated. The engineer might design safety roofs cover the walk path on the site. The entrance of the building where labours might gather tightly at the rush hour and the direction to human-related components which are close to the building can be instances [TB02]. Moreover, the passenger lift's area should be blocked from the walk path to prevent the accident which causes from falling objects [SC08].

5.5.7.4 Place where can be the final place to be decorated

The last phase of the construction is to redecorate everything on the site. Everywhere should not be left the mark or defect which indicates the construction had taken place. This principle has to be implemented with the equipment that has to be installed to the building, for example, the tower crane, the passenger lift, and the stationary concrete pump. However, other components on the site have to be managed by this principle also. The site office is the last component to be removed from the site. Therefore, the site office should be placed at the location where can be easily to be redecorated, for instance, the garden or the park of the finished project [SC04].

5.5.7.5 Material path

Although the site office and toilets should be placed out of the tower crane's coverage as the first rule, the construction sites nowadays have very little free space which makes planning difficult. From the multiple case study, the material path is the route which the material has to go through between storages and the constructing building. The area where the material path passes is risky for the accident of falling objects. Consequently, these human-related components have to be at least located out of this material path if they cannot be placed out of the tower crane's coverage [SC02 and SC05].

5.5.8 Specifications and regulations

This factor is about the restrictions which the engineer has to follow strictly. Otherwise, the engineer can be considered breaching the contract or be illegal. This factor can be separated into four sub factors, which are (1) specification from the owner, (2) regulations, (3) right of the land nearby, and (4) specification from the mobile cement plant's supplier.

5.5.8.1 Specifications from the owner

The owner might make requests which can alter the construction site layout. It can be seen in the multiple case study that one of the case (Case D) has a constraint from the owner. The owner asks to have the site office for their representatives and specifies to have at least 9 sq.m. workspace for each staff on the site. The experts respond to these requests by placing another site office for the owner's representatives and building the site office with the newly built method. Consequently, every site office of this case is very enormous comparing with other case studies because the area for the project manager on the site usually is 4 to 9 sq.m., and only 2 to 5 sq.m. for other staff [SR01, MP01, and MP02]. Moreover, the owner also holds the power to allow or reject the mobile cement plant. Although the engineer and the supplier would like to invest on the plant, the owner has the right to not allow the usage [SR06]. The suppliers can consider the specification from the owner also before they can reach an agreement.

5.5.8.2 Regulations

The regulation is one of the factors which the engineer has to follow strictly. The common regulations that the experts raised are about the dust, the smell, and the safety. First, the dust must be concerned and the engineer should design the layout which does not let the dust go out of the site. The mobile cement plant cannot be placed if the habitat stays nearby [LS06]. Second, the dust protection sheet should be used to cover the constructing building to prevent the dust from spreading outside of the site [SR08]. Third, the labour's toilet should not be located near the wall which has neighbourhood due to its strong smell [LS07].

5.5.8.3 Right of the land nearby

Normally, the tower crane cannot rotate out of the construction site. Anyway, in Case D, every expert plans nearly as same as each other about the positions of tower cranes. From that position, fixed jib tower cranes have to swing out of the construction site in order to reach some certain destination. It is revealed from the data validation process that the expert panel has the mutual consent about the concept of the right of the land nearby. The experts agree that tower cranes should not rotate out of the construction site unless the owner of the land where the tower crane trespasses gives approval to the contractor [SR03]. However, the engineer has to construct the safety roof if there are pedestrians walking pass [LS01].

5.5.8.4 Specification from the mobile cement plant's supplier

The principle to take care of the mobile cement plant can be categorized into two types. First, the mobile cement plant is placed in front of the site. This method can facilitate the mobile cement plant well. Concrete trucks can access easy and do not affect the traffic on the site strongly. Second, the mobile cement plant is located at the back of the site. This implementation answers to the environmental regulation effectively. It prevents the dust from going outside. However, experts agree that it should follow the specification from the supplier [SR07]. They usually desire their plant to be placed in front of the site because of the convenient transportation [SR04]. They can use the engineer's site as a hub and let their concrete trucks go to deliver their concrete at other sites.

5.5.9 Free space

The amount of the usable space is affected with numerous components on the construction site. The construction sites with less free space are more likely to have their layouts altered by time to time. The issues with free space can be categorized into three parts, which are (1) amount of the free space, (2) corners or niches on the site, (3) availability of truck's parking.

5.5.9.1 Amount of the free space

The amount of the free space can be utilized as a trigger to judge the site whether it is a cramped site or wide site. If the free space is more than 2,000 sq.m., that construction is considered as a wide site. The engineer can plan freely for the construction site layout. However, if the free space is lower than 2,000 sq.m., that construction is considered as a cramped site. The store and the site office should be moved into the building after the second or third floor is finished [FS06 and FS07]. The mobile cement plant cannot be utilized on the site also due to the lack of free space if the free space is lower than 1,600 sq.m. [FS04].

Moreover, the steel yard is also affected by the free space. The Graph B12 and Figure B1 in the appencdix B show that the size of the steel yard is a proportion with the ratio between free space and the area of the size. The formula derived of the size of the steel yard equals to the site area plus five times of the free space size and divided by one hundred as shown in Figure 5.7. All of the activities like bending and cutting will be performed here. If the answer is lower than 100, the engineer should consider to fabricate the steel from outside and transfer it to the site when it is going to be used [FS03]. On the other hand, if the value gained is more than 1,600 sq.m., the experts agree that using only 1,600 sq.m. is enough for utilizing as the steel yard [FS01]. Anyway, although the value is low or high, the steel yard should be managed with the "Stocking to sustain work flow" principle [FS02]. The stock on the site should be enough only to sustain the workflow before the ordering for the new workflow. The planner should not order too much steel to keep inside the site because it is a waste of free space and the dust can occur.

5.5.9.2 Corners or niches on the site

The labours' toilet is considered by the experts that it is not unsightly for visitors, referred to the summed indices in Table B9. Consequently, they agree with the statement that the labours' toilet should be located at corners or niches where it cannot be seen by visitors if it is possible [FS05].

5.5.9.3 Availability of truck's parking

From the data validation, experts suggest that there should be some space for trucks to be able to park on the site. There is a further suggestion about the size of the trucks parking. The trucks' parking area should be huge enough that trucks can park for at least two trucks, so the size should be around 3x12 or 6x6 metres on the site [FS09]. This space can assist the concrete pouring to be continuous. Furthermore, it can be used as the delivery spot also.

5.5.10 Man power

The work plan does not tell only the work processes on the site. It can tell the number of labours to be hired for each work also, which can be used as the sub factor for certain components. The organization chart is also important for this factor because it can tell the number of staff, which is one of the sub factors belong to this factor.

5.5.10.1 Number of labours

The number of labours accounts to the hugest amount of labours each day. The components on the site have to be able to support that quantity. The components affected by the number of labours are the toilet and the passenger lift. The toilet should have the number of rooms which conforms to the labour legislation. It can be separated into 4 cases. First, if the labours do not exceed 15 people, there should be at least 2 rooms. Second, if the labours are around 16 to 40 people, there should be at least 4 rooms. Third, if the labours are around 41 to 80 people, there should be around 6 rooms. Finally, if the labours are more than 80 people, there should be at least 6 rooms with an extra room for each 50 labours [SR02]. Next, the passenger lift is agreed by the expert panel that each passenger lift can deliver 200 people [DB17].

This number can be the initial amount of the passenger lift before edition by other factors.

5.5.10.2 Number of staff

The staff in this case are the people who should have their own seats on the site. The site office is directly influenced by this number. The traditional way to calculate the size of the site office is to multiply the number of staff with the area of each person. The area of each person is separated by their position also. The expert panel suggested that in order to simplify the calculation, it should be categorized into two groups which are project managers and the others. The area for project managers is 4 to 9 sq.m. each, while, 2 to 5 sq.m. is the area for other positions. These numbers are gained from the data validation [MP01 and MP02].

5.5.11 Availabilities of components

The engineer should consider using the equipment or material which he has first. Al Hattab et al. (2014) reported that purchasing and rental cost are two major expenses of equipment. Using previous equipment means that it can eliminate and save these costs. This factor is applied to the tower crane, the passenger lift, the concrete pump, the site office, and the store from the multiple case study and the suggestion of the validation [CA01, CA02, CA03, CA04, and CA05].

5.5.12 Duration of the project

The expert panel agrees that the high-rise building project which has the duration lower than two years can be considered as a short project. More equipment might be considered to be implemented. The concrete pump, the tower crane, and the passenger lift have to be able to sustain all of the work from the tight schedule [DP02, DP01, and DP03]. The duration of the project can also justify the type of the site office, whether they should be either prefabricated or newly built. The trigger separated these two usages is two years. The site office should be prefabricated, unless the duration of the project is more than two years [CC11, CC12, and CC13].

5.5.13 Type of the building

Due to the scope of the study, the knowledge rules are constructed base on the reinforced concrete high-rise building construction. Other types of building project should be consulted with care. From all of the summed indices and data validation, tower cranes, passenger lifts, and concrete pumps have to be utilized in order to raise the productivity of the work [TB01, TB03, and TB04]. The protection, both at the building and the boundary of the site, are also needed for the high-rise construction project [TB02].

5.5.14 Result

From the multiple case study, Table 5.9 shows the number of sub factors and affected components of each factor influencing the construction site layout. The design of the building has the hugest number of sub factors, followed by the constraints of components and relationships between components. However, the design of the building affects only four components on the construction site, lower than half of the factors in the table. On the other hand, the site constraints and the traffic of the site play the most vital roles for the construction site layout when based on the number of affected components.

For the frequencies, the design of the building plays vital role for tower cranes and passenger lifts. The planner cannot manage them unless the design of the building is ready. The site constraints are important for the planning of the site office because the free space on the site can indicate the type of the site office. Moreover, its location depends on the site also. It has to be located in front of the site where can be furnished later. The relationships between constraints are a powerful factor influencing the toilet. The planner has to place toilets in the safe place due to the safety of employees who use the facility. However, if the location is too far, it will increase the idle time of employees on the site and decrease the productivity of the site. This is a delicate problem that the planner has to manage. Tower cranes and concrete pump have numerous constraints in themselves. The planner has to fulfil these limitations to prevent the loss from the implementation. Finally, the location of the site and the specifications and regulations impact the usage and management of the mobile cement plant on the site powerfully. The planner has to be cautious with confinements that can restrict the utilization.

Table 5.9 Number of sub factors and affected components of each factor.

Factors	Sub factors	Affected components
Design of the building	12	4
Constraints of components	11	6
Relationships between components	7	6
Method of work	5	5
Location of the site	5	6
Site constraints	5	7
Specifications and regulations	4	5
Traffic on the site	3	7
Free space	3	6
Man power	2	3
Availabilities of components	1	5
Duration of the project	1	4
Type of the building	1	4

Table 5.10 shows the breakdown frequencies of all sub factors about their influenced components. Abbreviations of each factor are shown in the Table 5.11. It can be seen that the only type of components which is affected by the design of the building is the equipment. Consequently, the building plan is very essential to CSLP for the equipment. On the other hand, factors from the site plan influence every type of components except the equipment. Therefore, experts can gain the overview of the location of storages and human-related facilities by having the site plan. The planner does not have to wait for the design of the building in order to start managing the construction site layout. The work plan greatly affects the human related components, while also influences the storages and equipment. Other factors affect the equipment and human related facilities. There are slight differences that the availability and constraints of components have power on the equipment, human related facilities, and storages, but do not affect the storages. While, the location of the site, specifications, and regulation affect the equipment, human related facilities, and others components, but do not influence storages.

Table 5.10 Breakdown frequencies of each factor

Components		Building plan			Site plan			Work plan			Others				Total
		DB	DP	TB	FS	TS	SC	MW	MP	CR	CA	CC	LS	SR	
Equipment	Tower crane	6	1	1				2		1	1	4	1	1	18
	Passenger lift	5	1	1			1	2	1		1	1			13
	Concrete pump	5	1	1		1					1	3	1		13
	Mobile cement plant	1			1	1	1						2	3	9
Human related	Site office		1		1		3	1	1	1	1	1		1	11
	Toilet				1		1		1	4		1	2	1	11
	Store				1	1		1		1	1	1			6
Storages	Steel yard				1	1		1		1		1			5
	Laydown area					1	2			1					4
Other	Protec-tion			1			1						1	1	4
	Trucks parking				1	1							1		3
	Entrance gate					2	1								3

Table 5.11 Abbreviations of factors

Abbreviations	Components
DB	Design of the building
DP	Duration of the project
TB	Type of the building
FS	Free space
TS	Traffic on the site
SC	Constraints of the site
MW	Method of work
MP	Man power
CR	Relationships between components
CA	Availabilities of components
CC	Constraints of components
LS	Location of the site
SR	Specifications and regulations

For the frequencies, the design of the building plays vital role for tower cranes and passenger lifts. The planner cannot manage them unless the design of the building is ready. The site constraints are important for the planning of the site office because the free space on the site can indicate the type of the site office. Moreover, its location depends on the site also. It has to be located in front of the site where can be furnished later. The relationships between constraints are a powerful factor influencing the toilet. The planner has to place toilets in the safe place due to the safety of employees who use the facility. However, if the location is too far, it will increase the idle time of employees on the site and decrease the productivity of the site. This is a delicate problem that the planner has to manage. Tower cranes and concrete pump have numerous constraints in themselves. The planner has to fulfill these limitations to prevent the loss from the implementation. Finally, the location of the site and the specifications and regulations impact the usage and management of the mobile cement plant on the site powerfully. The planner has to be cautious with confinements that can restrict the utilization.

5.6 Comparison between the critical index and the number of factors

The guideline of CSLP is possible to be achieved by only the exploratory interview. However, managing the construction site layout has numerous details and factors affecting the planning. It is inconvenient for experts to think and describe in words about what they are thinking. It may lead to the misunderstanding and misinterpreting. Furthermore, indiscreet interviewing let experts to have more freedom to recall about their past work experiences that varies from every individuals. Consequently, each expert relies on the procedure which they are familiar with, and makes the answers being harder to be categorized.

From the reasons above, only data from the exploratory interview cannot be used to form a knowledge base of the entire CSLP. There should be more data collections to compare and check with the data from the exploratory interview. The multiple case study is therefore appropriate as another data collection method due to its suitability with the question which requires factors behind the phenomenon and cannot be replicated. The multiple case study can assist to gain the in-depth reasons of the situation from the similarities and differences between cases also. This implementation can eliminate the uncertainty from the past experience of experts and let the expert panels to have the same point of view about the construction site layout.

Table 5.12, derived from Table 5.8 shows the number of sub factors and factors affecting each component. It can be seen that the top most affected components by CSLP are equipment, which has numerous sub factors. Human related facilities follows the equipment as the second ranked type of components. Storages gain the third rank and the other components get the last rank. However, the critical index from the exploratory interview in Chapter four does not reflect the same sequence of rank as the multiple case study showed.

Table 5.12 Numbers of factors affected each component

Components	The number of sub factors affecting the corresponding components	The number of factors affecting the corresponding components
Tower crane	18	9
Passenger lift	13	8
Concrete pump	13	7
Site office	11	8
Toilet	11	8
Mobile cement plant	9	6
Store	6	6
Steel yard	5	5
Protection	4	4
Laydown area	4	3
Trucks parking	3	3
Entrance gate	3	2

Table 5.13 shows the rank of the importance for each component from the exploratory interview. The entrance gate gains the most score of importance equals to the tower crane, but it has the lowest number of factors affected. This conflict means that experts pay attention to the entrance gate abundantly, while there are few factors influenced the planning for the entrance gate. The steel yard also receives the over care having the same level of importance as the other equipment, although it has hardly any factors affected comparing to them. On the contrary, the toilet gains only moderately importance, while it has the larger number of factors affected comparing with the store that has four scores of critical index. Nevertheless, it can be seen from the comparing between Table 4.2 and Table 5.13 that information from experts are reliable due to verifying from data triangulation. These two methods have the same

direction for the components which have lower or equal to three scores of critical index. They are eliminated out of the planning in the multiple case study by the expert. Components in bold characters are shown in layouts of the expert panel.

Table 5.13 Ranks of the importance for each component from exploratory interview

Rank	Components
5 (The most important)	**Entrance gates and** **Tower crane**
4 (Important)	**Concrete Pump,** **Passenger Lift,** **Site Office,** **Steel Yard, and** **Store**
3 (Moderately important)	Cement Store, **Mobile cement plant,** Fabricated rebar yard, Formwork storage yard, Guard House, **Laydown area,** Temporary Transformer, **Toilet,** Truck's tires washing yard, Waste chimney, and Welding shop
2 (Less important)	Water Tank
1 (The least important)	Fabricated formwork yard, Parking lot, and Service Workshop

5.7 Guidelines for CSLP

In order to provide more benefit for the low expertise engineers, the knowledge after analysed and concluded has to be simple to understand the whole picture of CSLP. The guideline is chosen to be the way to present the result of the study. The user can follow the flow of the guideline which is easier to understand through plain texts. The guideline is constructed by the summation of every rule bases, categorized into three phases of CSLP. These three phases are named "Early stage", "Middle stage", and "Checking stage". First, the early stage is started by gathering all of the available primary data. Each part of the guideline in this phase is clustered by sources which the engineer can gain the information from. These sources are (1) detail of the project, (2) work plan, and (3) other sources.

The detail of the project can be separated into smaller groups by the type of the document. The building plan can give the information about the building, for instance, the size, the shape, the height, properties of walls, and positions of cores. Next, the site plan can provide the data of the construction site, for example, the size, the shape, the accessibility of trucks. Finally, the detail of the construction can provide the amount of the concrete usage and the duration of the construction.

Second, the work plan is a document about the work processes of the construction. It usually consists of the bar chart telling which work will take place on the site at which duration. The work plan is crucial for the construction project because the engineer can plan for the labour management. Each work can be specified the exact number of labours who has the responsibility over each job, which these numbers can be summarized into the number of labours on the site for each day. Moreover, it can inform the engineer about the equipment and materials to be utilized at the specific moment. The engineer can plan for the purchasing, stocking, and using plans for these equipment and materials. Lastly, the number of staff can be found from the organization chart on the site. It is a document showing employees on the site with their duties and positions.

Finally, information from other sources is the data which cannot be obtained from the building design and site plan. The specifications of the owner and other parties have to be fulfilled in order not to breach the contract. The regulations must be followed unless the site will have problems with authorities. The site visiting is also necessary for obtaining the constraints on the site, the condition of the traffic, and the environment of nearby neighbours. The equipment and materials in the stock of the engineer is also important. The cost of purchasing or renting can be saved by using the already owned equipment and materials as mentioned in the previous topic.

Once all of the information is ready, the user can follow the guideline by input all of values of factors into the guideline. For example, the engineer can investigate into building plan to know the height of the building. The engineers can know the primary principle to treat the equipment affected by the height of the building, which are the tower crane, the concrete pump, and the passenger lift. Then, the engineer can continuously look forward to other factors, for instance, the shape, properties of walls, and the positions of cores, to gain more constraints and theories which are suitable to manage the planning for the interested project. The guidelines for the first stage are shown in Figure 5.6 to 5.12. When every variable from information sources is ready, the engineer can continue to the second phase of the planning, the middle stage. The engineer can gain the possible locations of components when the first phase of the planning is finished. Moreover, some components can be specified their properties with only the primary factors. The types, the size, and the location of components can be indicated in this phase. These components are the laydown area, the store, the steel yard, and the possibility to utilize the mobile cement plant. They can be planned due to their natures which have only small number of factors related.

The middle stage specifies the properties of equipment and human related components. For the storages and the store, the engineer can get enough constraints from the early stage. In this stage, the guideline can guide the planner approximately. The planner has to do the decision making by himself. The guideline can only give advice and specify the frame of available choices which the planner can choose. For example, the guideline can specify choices and suggestions for the choosing of tower cranes by displaying the available jib types and radiuses, while, the concrete pump can be selected whether it is a stationary type or mobile type based on factors of the projects. The result from this stage is that each component can be placed on the construction site at the possible location after the planner considers every property already. The full guidelines of the second phase are shown in Figure 5.13 to 5.14.

Finally, the last phase of the planning is the checking stage. The objective of this phase is to raise the ability of the planning, so it can support the work and eliminate the risk of accident based on relationships of components. The most critical concern is the coverage of tower cranes. The engineer has to check whether all of storages are covered with the coverage of tower cranes, while human related components should be placed out of the path which the material is transferred. Other factors are the availability of the trucks' parking area, the principle treating walk paths on the site, and the relationship between components. The last part of the guideline is shown in Figure 5.15 to 5.16.

5.8 Conclusion

In this chapter, the methodology to collect the in-depth data and the data analysis are presented. The multiple case study is implemented as the second data collection due to its ability to gather knowledge behind the real practice. Five different cases are selected as case studies to let the expert panel manage CSLP. The similarities and differences between the layouts are shown through the summed indices, formed by tabular method for each variable on the construction site. The attributes that separate each variable in each layout are gathered from the exploratory interview in Chapter four. The clustered answers from experts are utilized as the header of tables. However, these headers are not fixed. It can be added, deleted or corrected after the analysis in order to represent the real practice and be able to extract the knowledge behind decisions from experts. The components which appear in every layout are classified to be analysed in this stage. Although the data from exploratory interview pointed out that the component on the site should be separated into three groups, the data from the multiple case study indicate that they should be separated into four categories instead. The first category is the equipment which consists of tower cranes, passenger lifts, concrete pumps, and the mobile cement plant. Next, the second class is the storages which are the steel yard and the laydown area. The third type of components on the construction site is the human related facilities. These constituents are composed of site offices, toilets, and stores. Finally, the last type of the component is categorized as the other components, which are the protection, the parking area for trucks, and the entrance gate

The data of each attribute are analysed, concluded, and formed into rule bases. These rule bases are summarized and gathered into a survey. The data validation uses this survey to gain the approval from the expert panel that the interpreting is correct. Rule bases which get lower than four score from five is eliminated, while the rule bases which have more than or equal to four are corrected if there are suggestions

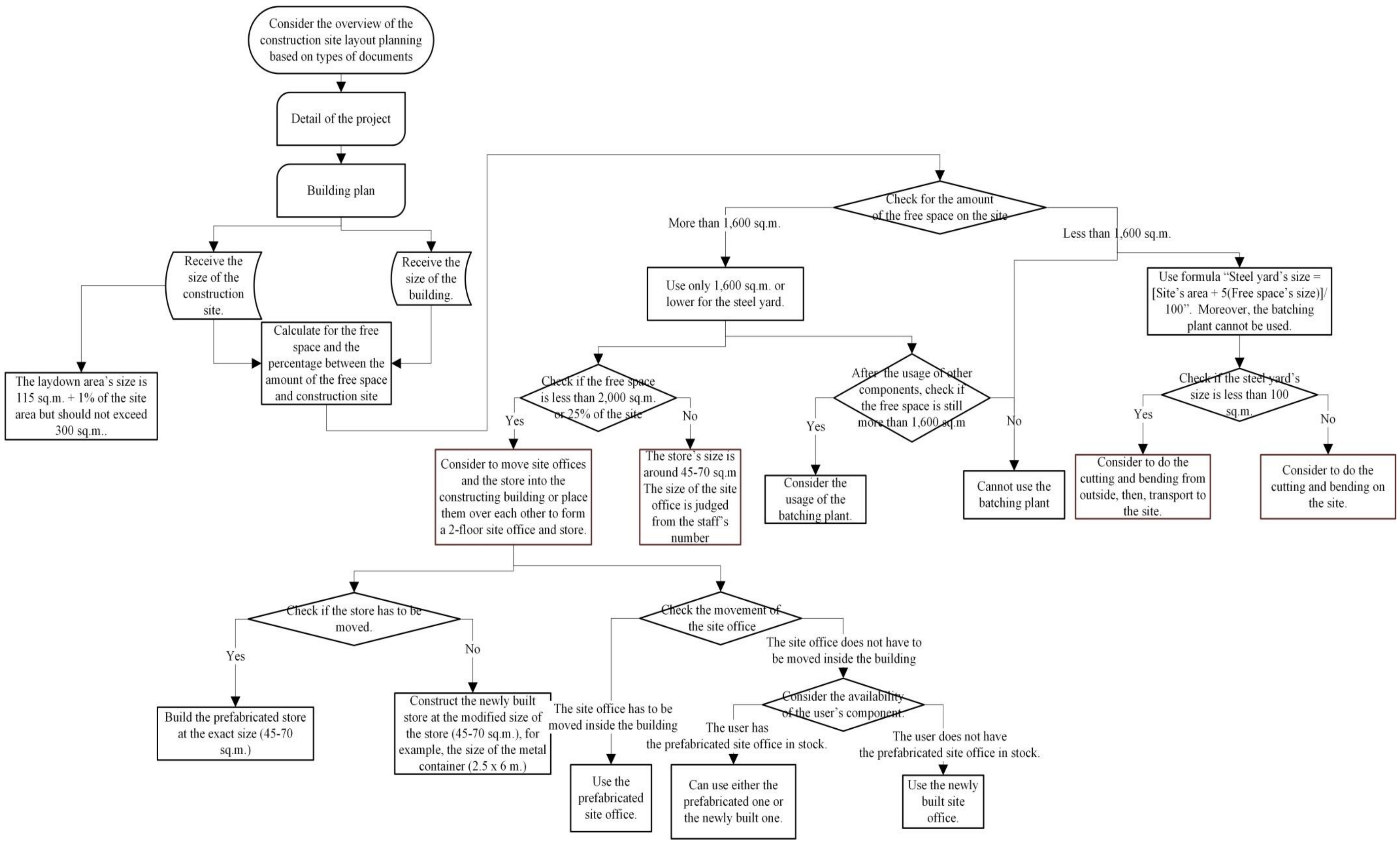


Figure 5.8 Guideline for the construction site layout planning in the first phase part 1

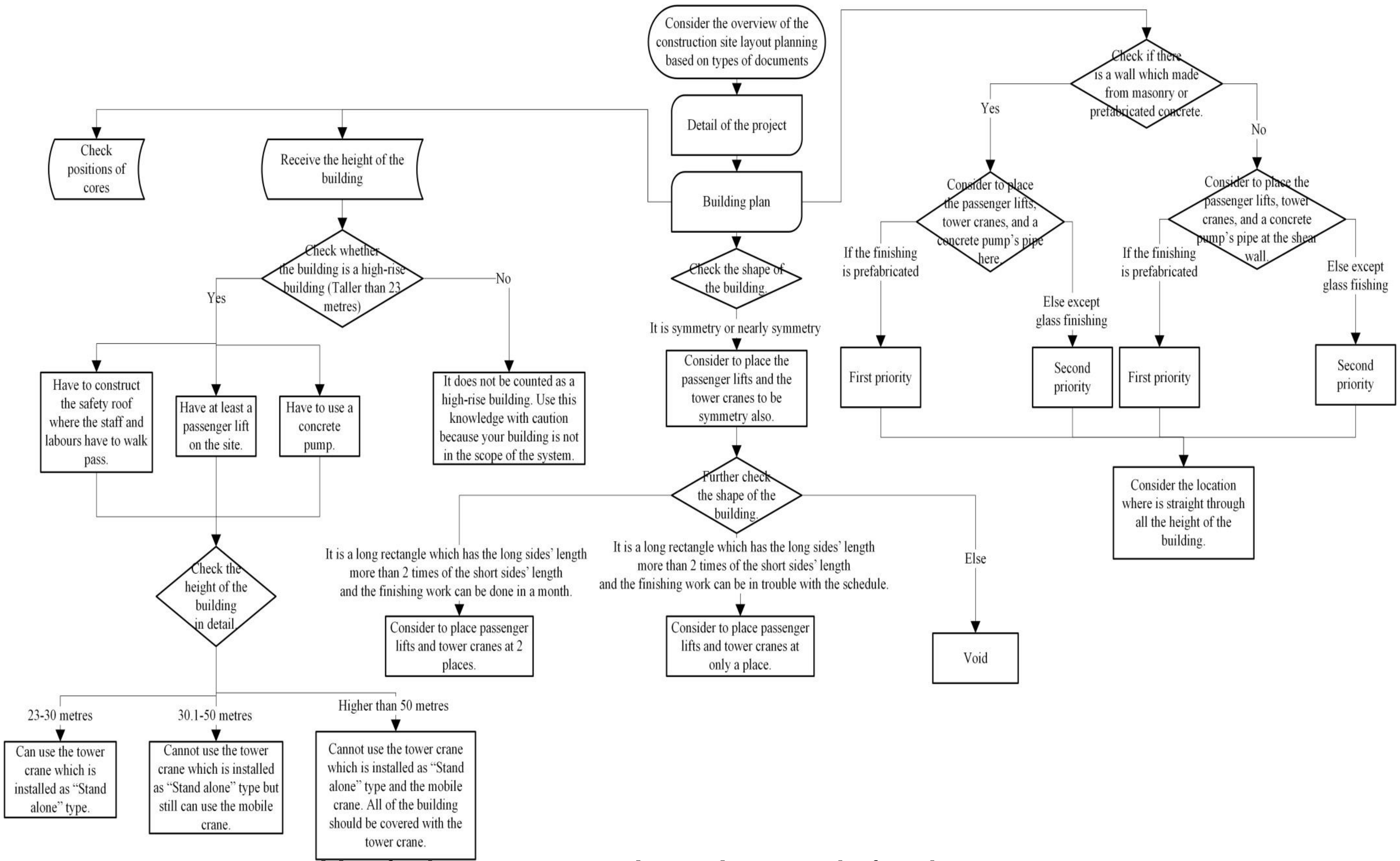


Figure 5.9 Guideline for the construction site layout planning in the first phase part 2

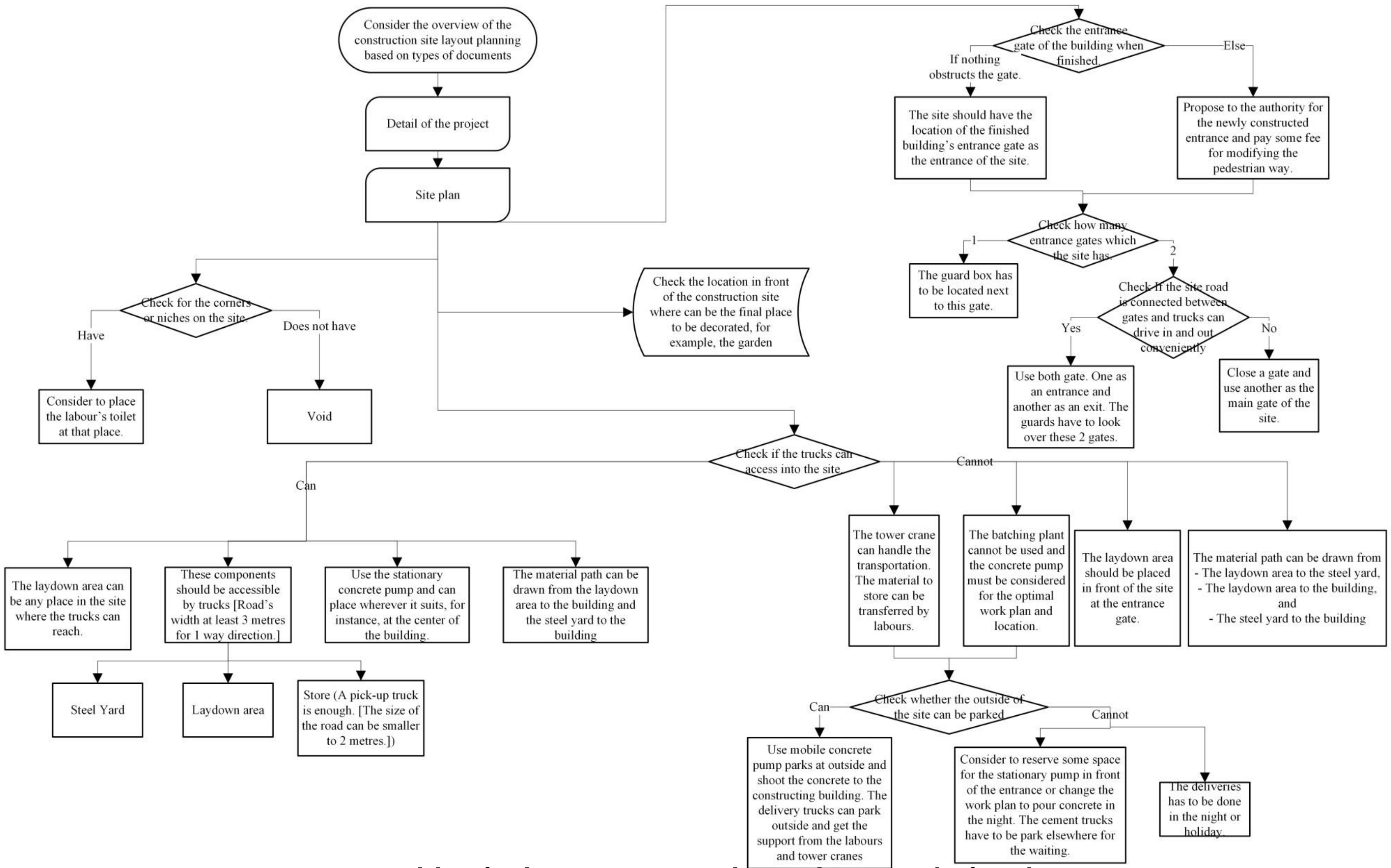


Figure 5.10 Guideline for the construction site layout planning in the first phase part 3

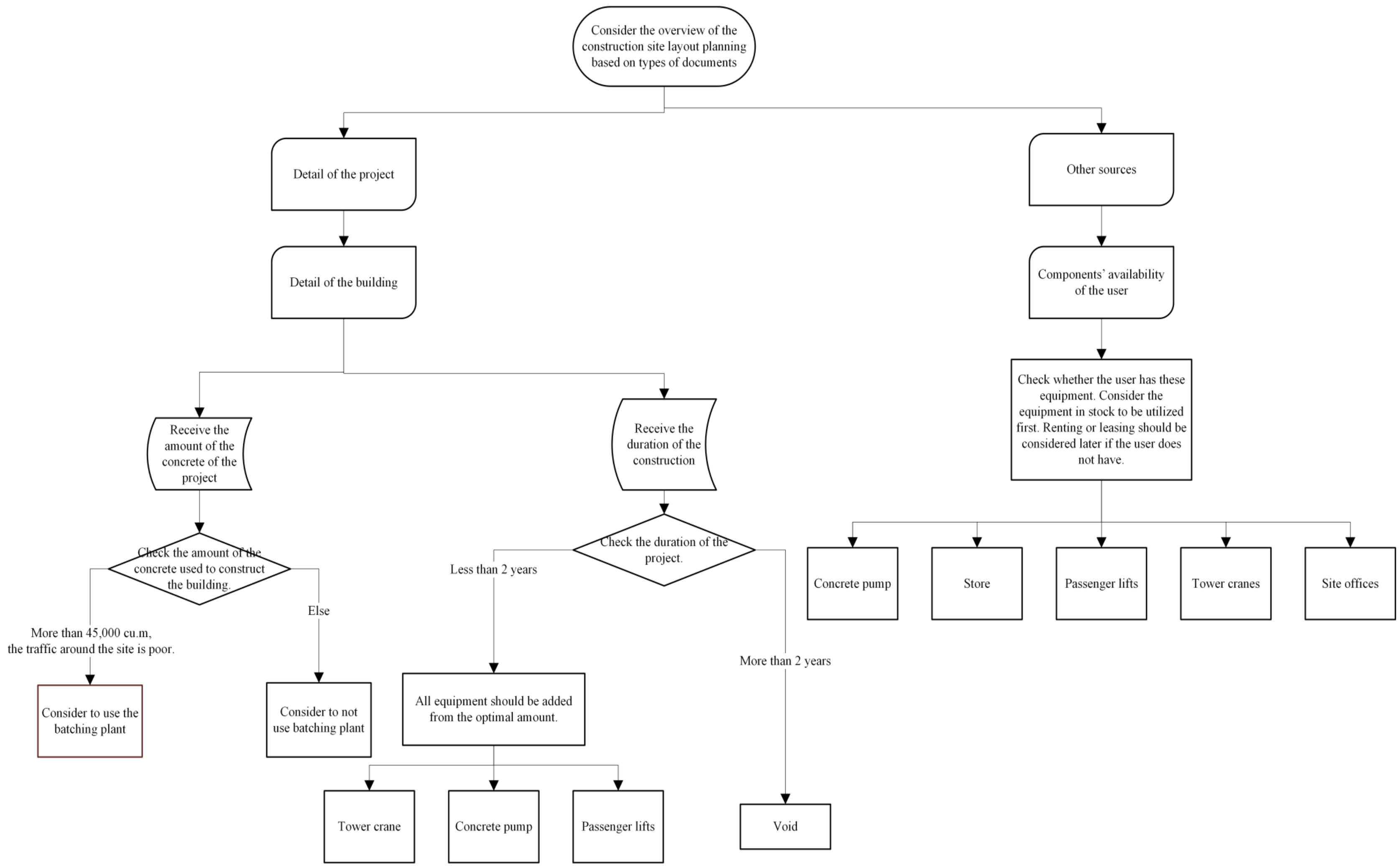


Figure 5.11 Guideline for the construction site layout planning in the first phase part 4

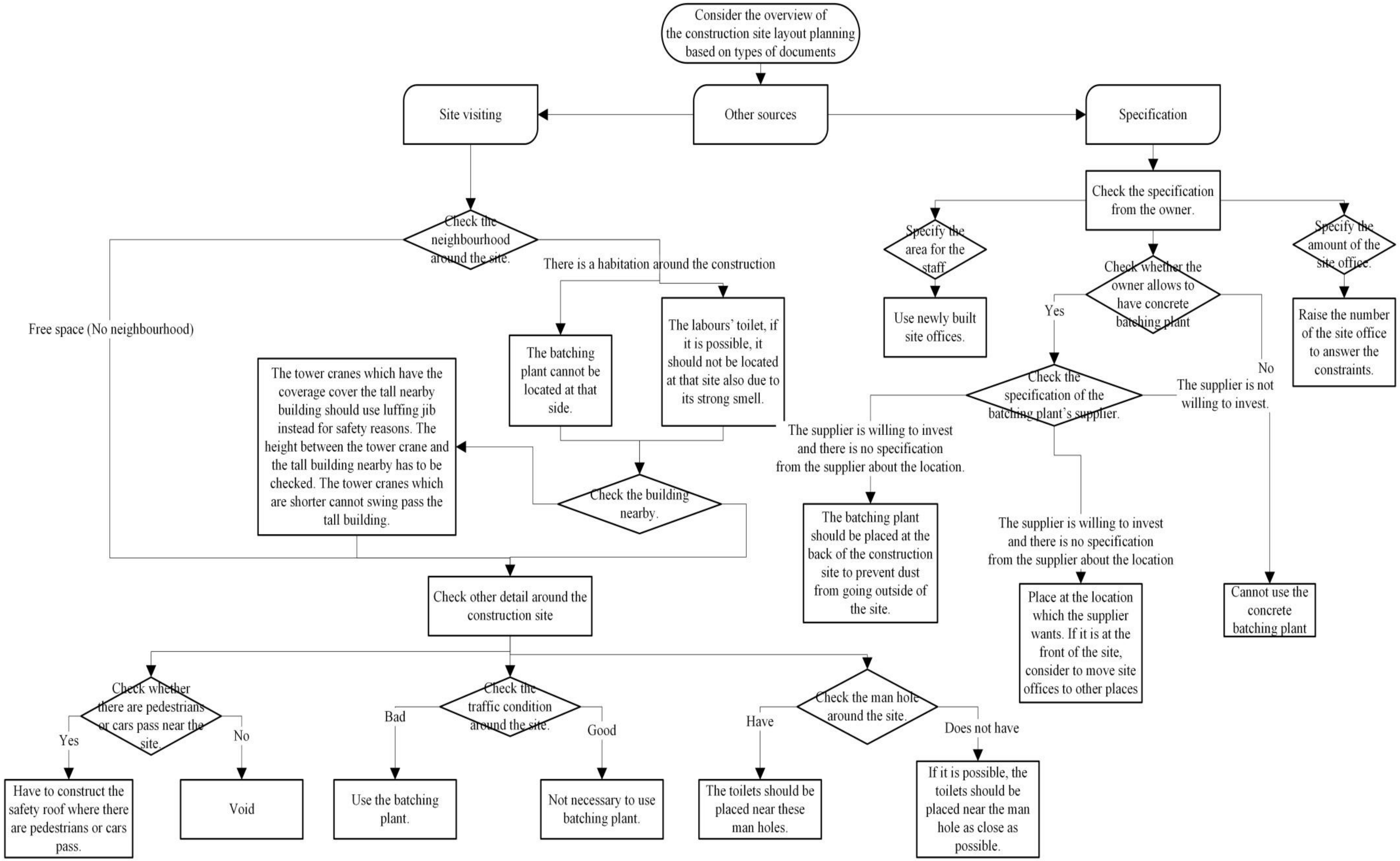


Figure 5.12 Guideline for the construction site layout planning in the first phase part 5

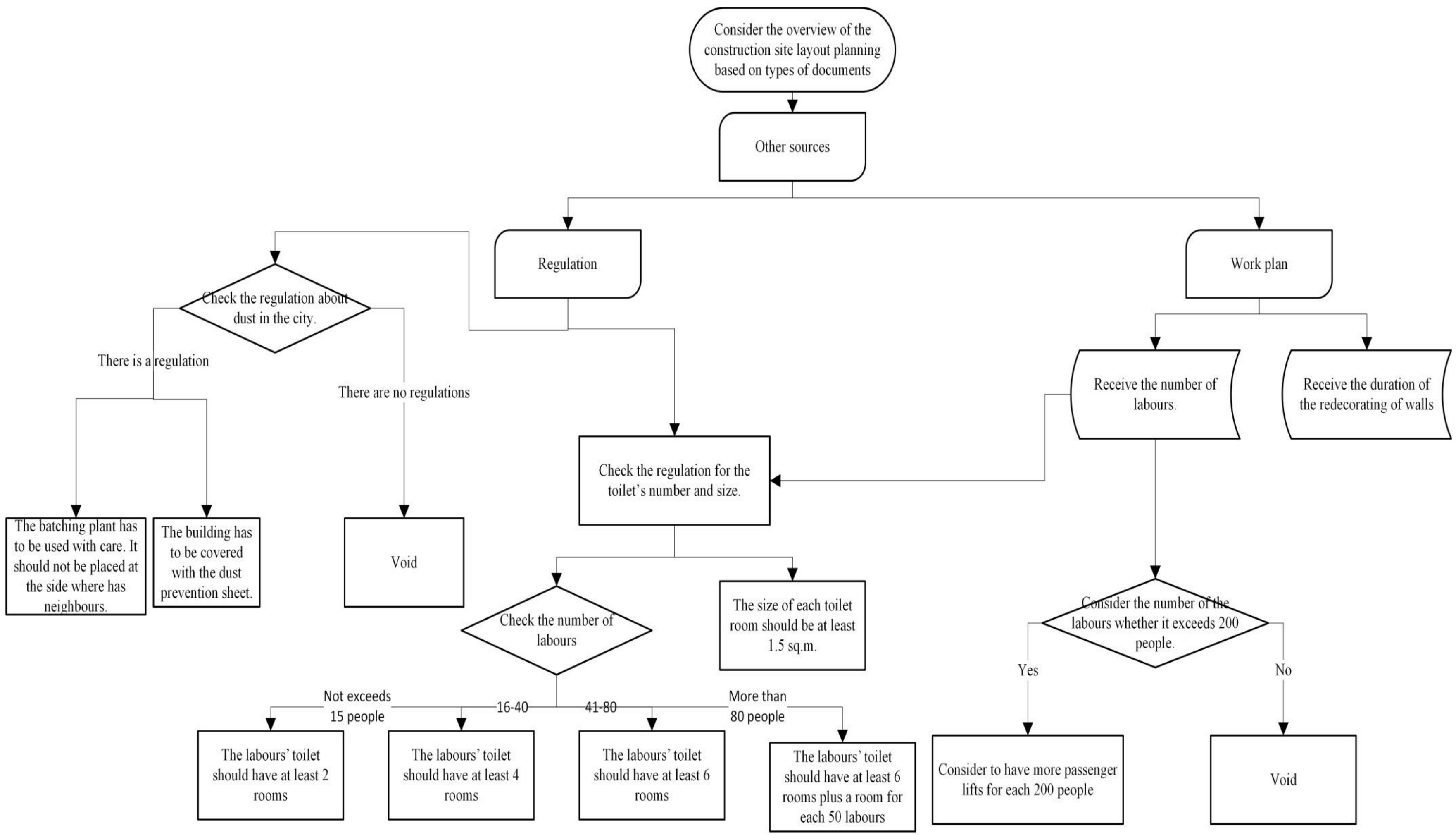


Figure 5.13 Guideline for the construction site layout planning in the first phase part 6

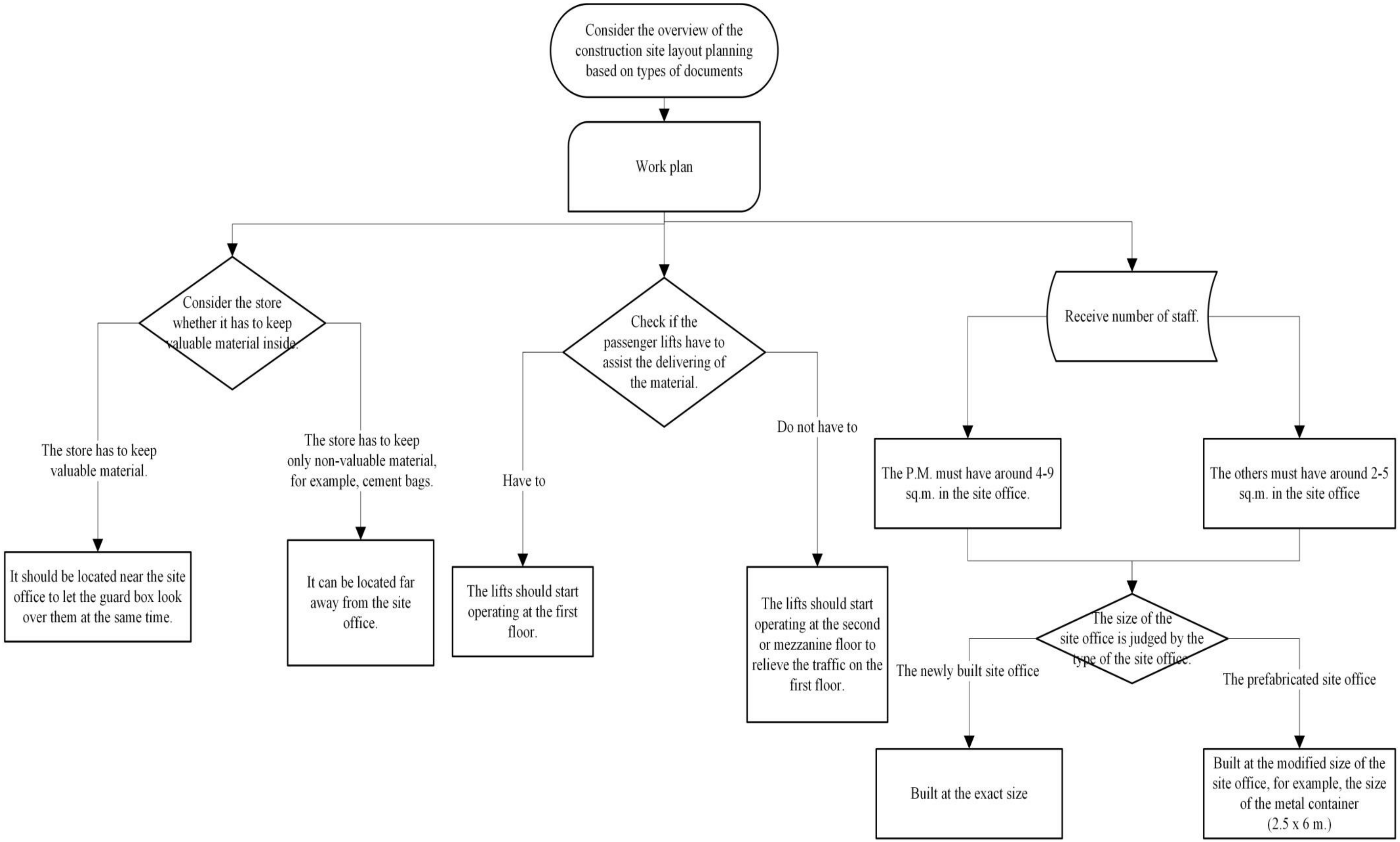


Figure 5.14 Guideline for the construction site layout planning in the first phase part 7

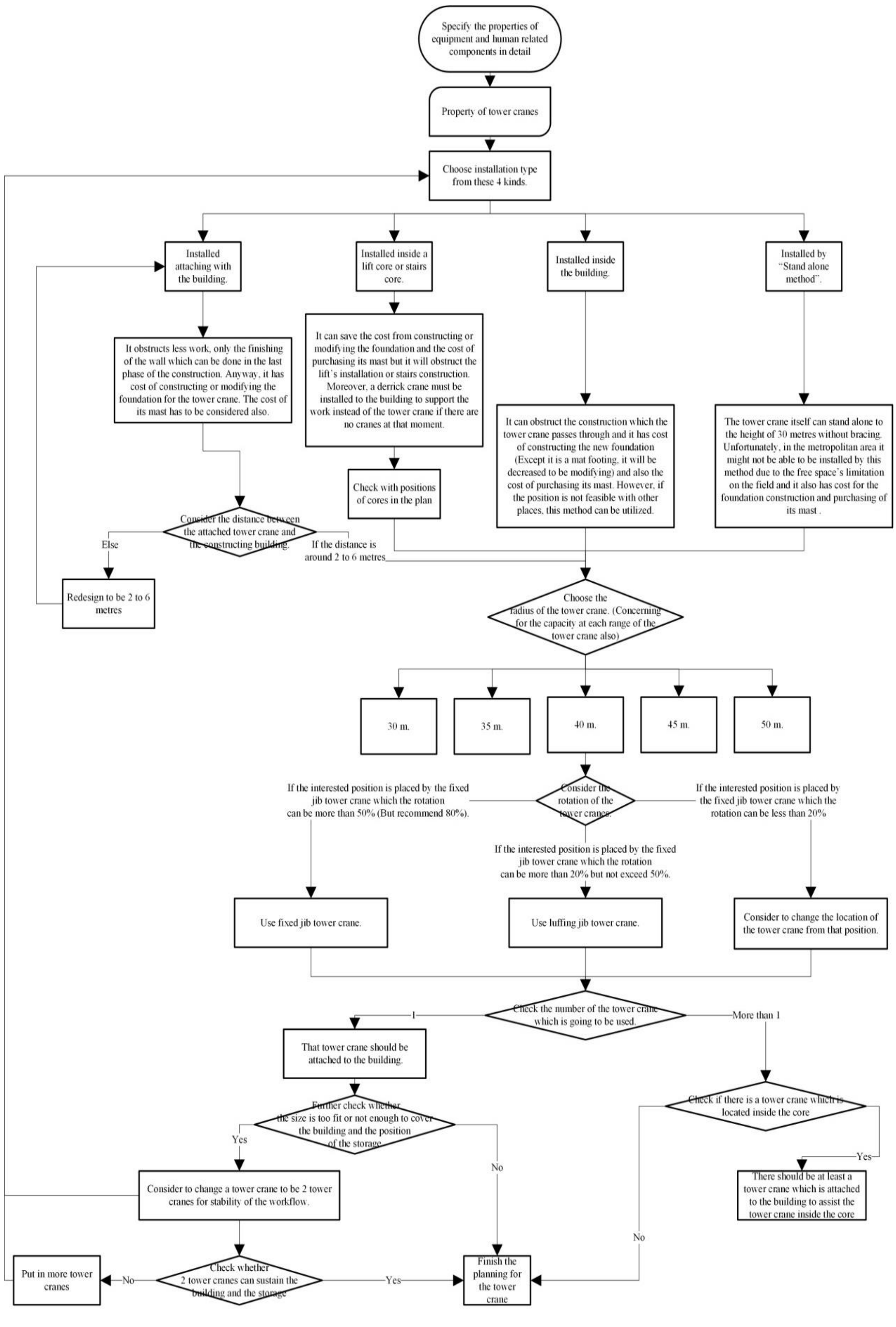


Figure 5.15 Guideline for CSLP in the second phase part 1

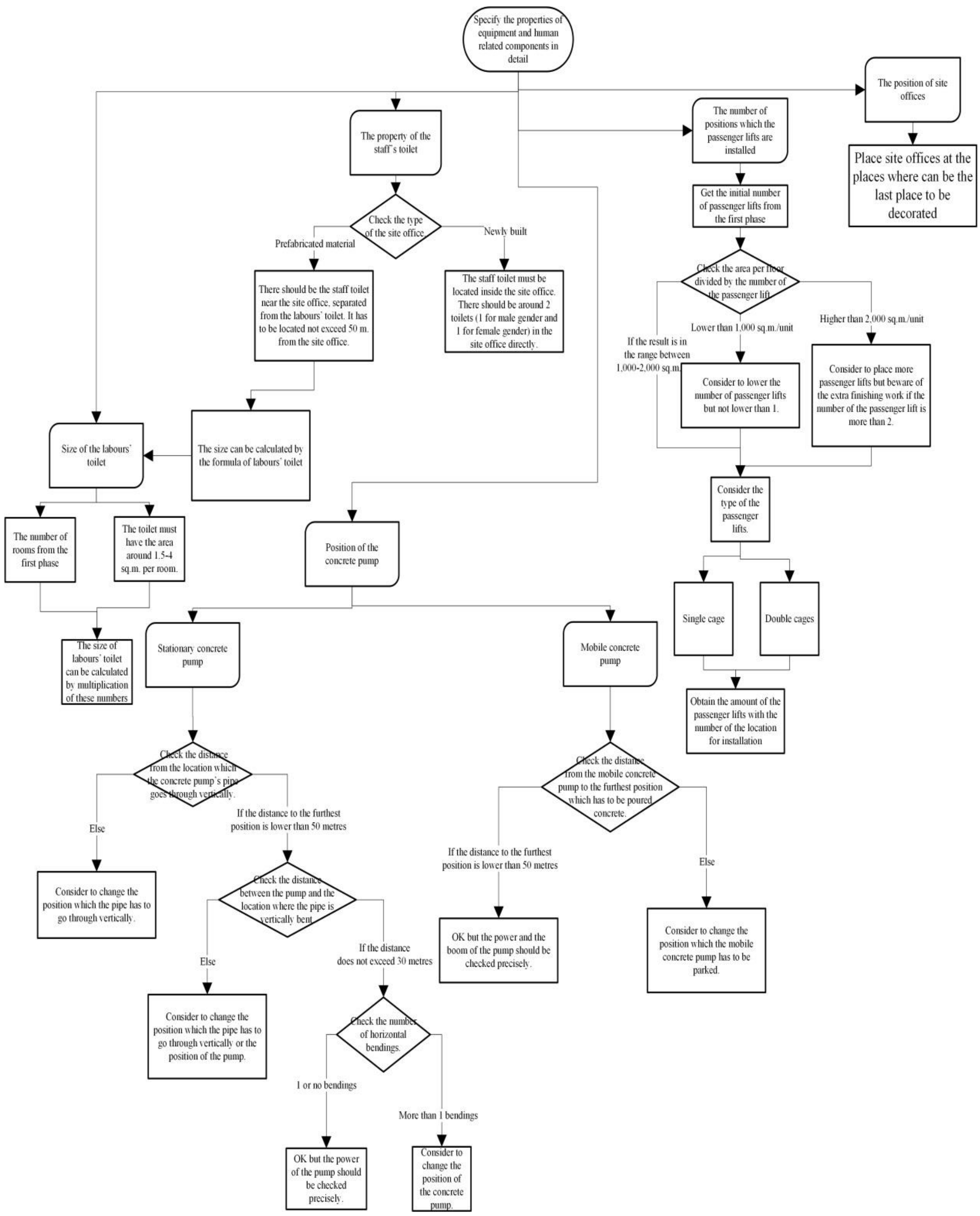


Figure 5.16 Guideline for CSLP in the second phase part 2

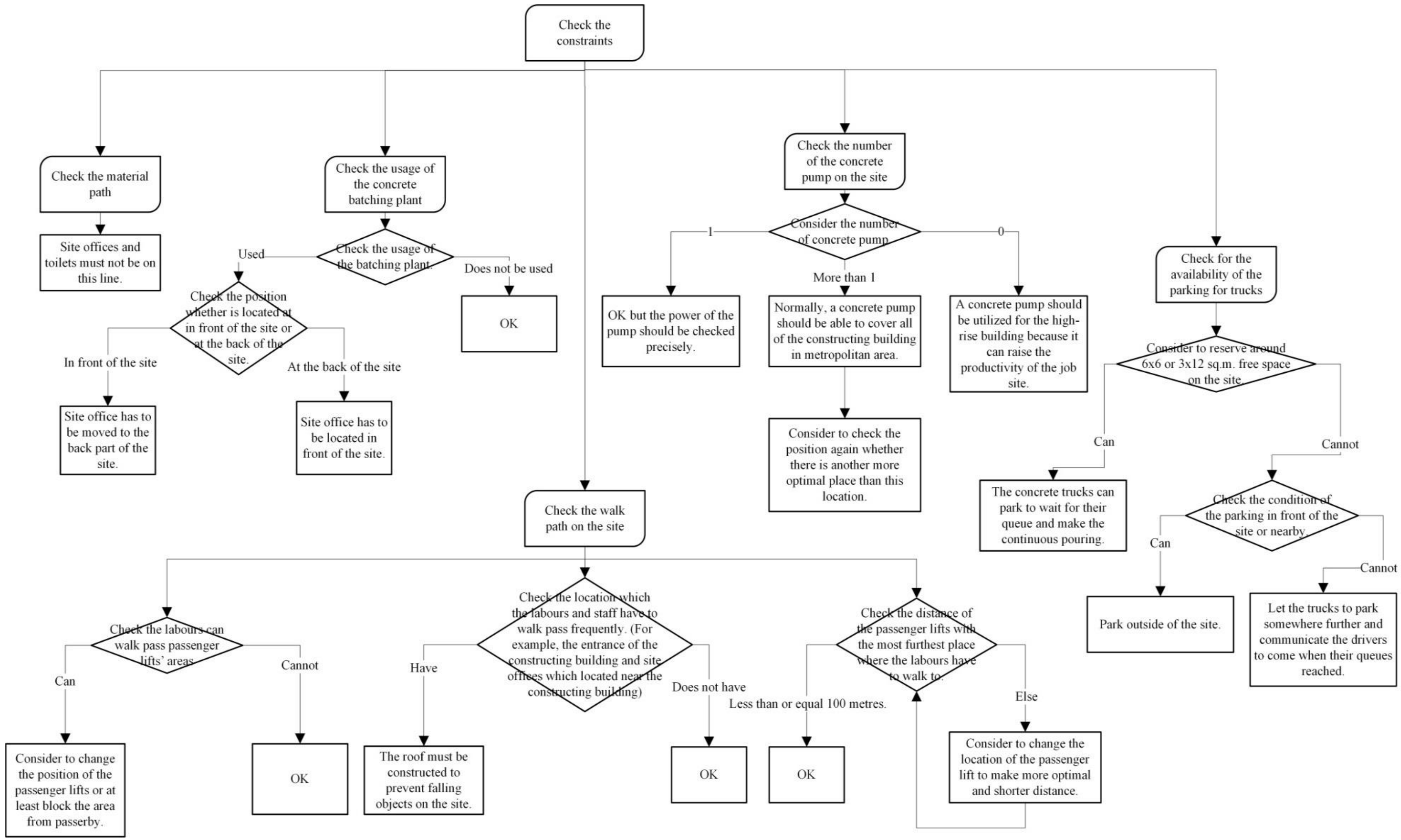


Figure 5.17 Guideline for the construction site layout planning in the third phase part 1

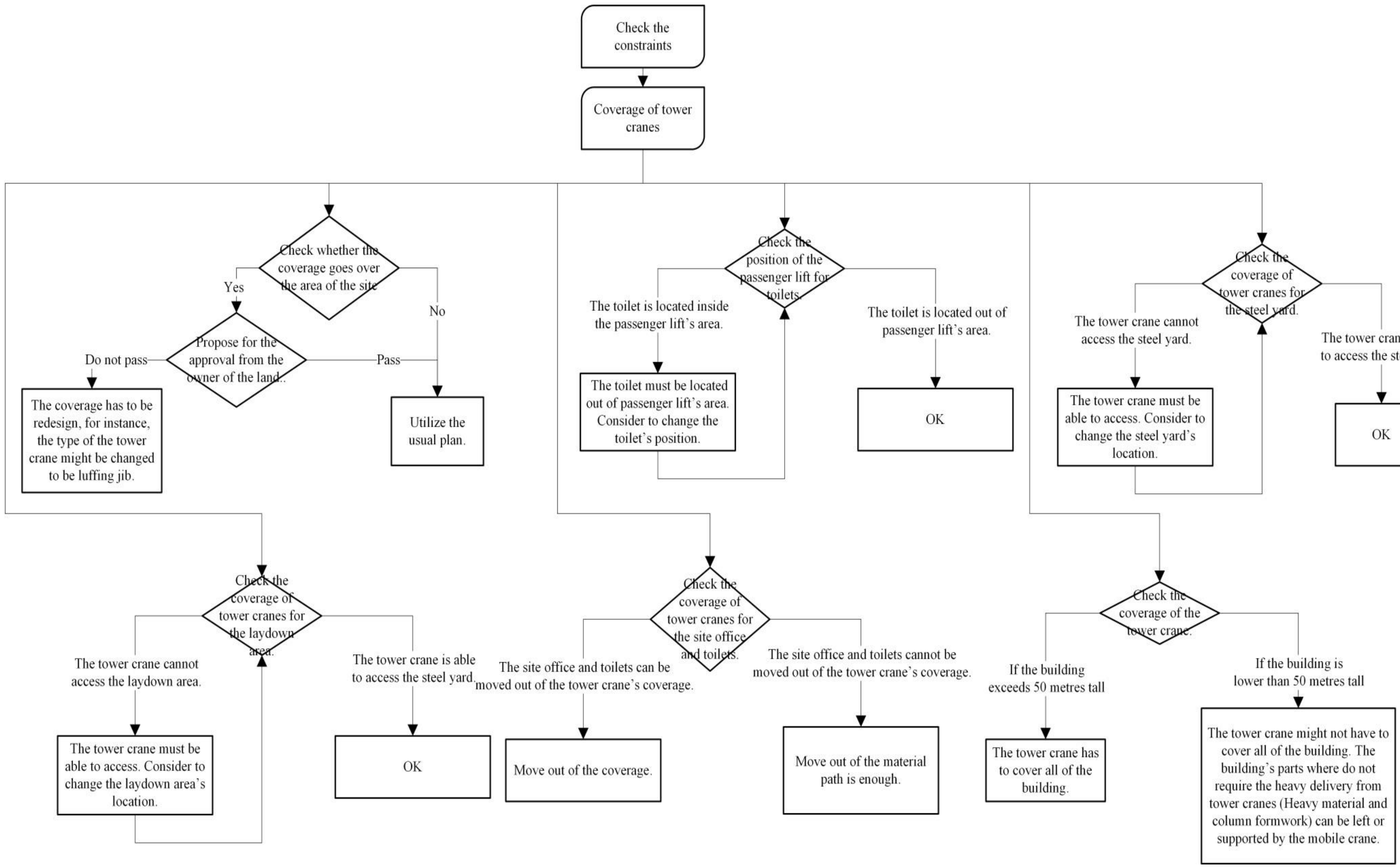


Figure 5.18 Guideline for the construction site layout planning in the third phase part 2

from the experts. The knowledge rule bases after gaining the correction and approval by the expert panel are drawn into the guideline for CSLP. All of the factors affecting decisions are collected and presented as well.

From the multiple case study, there are thirteen factors affecting CSLP. The factors which have the greatest number of sub factors influence to components on the site are the design of the project, the constraints of components, and the relationships of components. The components that have the hugest number of sub factors affected are the equipment, which are the tower crane, the passenger lift, and the concrete pump. Next, the result from the multiple case study is compared with the data from the exploratory interview. It is revealed that equipment is the type of components on the site that experts agree they are the most critical type for CSLP. However, there are differences between these two findings. Storages gain moderate attention from experts in the exploratory interview but the factors from multiple case study report that there are few factors that affect them. The entrance gate also has small number of factor affected but gains high attention from the expert panel. On the other hand, the toilet which experts said it does not have to be considered abundantly has numerous factors influenced. From these conflicts, it can be concluded that there is a contrast between the thinking of experts about the importance of components and the number of factors which experts have to treat them. Consequently, CSLP is varies. Thus, precise data from interviewing might not be able to catch all of the knowledge and factor behind each decision. The multiple case study is more suitable to the question which requires in-depth answers and would like to know factors that altered the phenomenon. This method can assist the study by replicating the real practice and extracting facts behind the planning.

The guideline is presented to assist the low expertise engineers who have to manage CSLP. It can be applied to the benchmarking between the existing site layout and the guideline to check whether the interested site layout can be improved. The guideline is displayed into two versions. The first one is the overview of CSLP. It is separated into three phases: Early stage, middle stage, and checking stage. The second version is focused on each component to concentrate on the principle treating components by components

Chapter 6
System development

6.1 Introduction

In this chapter, the development of the system for CSLP is presented. It can assist the planning for the low expertise engineer by receiving the value of factors affecting the planning and giving suggestion according to the knowledge base inside the system. The planner can plan along with the suggestion to achieve the construction site layout which can be workable based on the knowledge of the expert panel. The application is a knowledge-based system developed by the software “Ren’py”. Moreover, the principle and work procedure inside the system are also presented. This chapter is separated into 4 topics, which are (1) introduction, (2) system planning, (3) process of the system development, and (4) conclusion.

6.2 System planning

The main objective of the system is to assist CSLP based on the knowledge of experts in the previous chapter of the study. The guideline in Chapter five acts as the core process of the system. The system also separated its process into three phases, which are, early phase, middle phase, and checking phase. The base hardware used to develop the system is a laptop computer. The software which the system is developed called Ren’py. The name of the proposed system is *CU-Site*.

The system can be divided into three parts. The first part is the main mechanism which acts as the body of the system. This module interacts the user by requesting the values of factors inside the system, receiving the values, transferring the values through the knowledge rule bases, and returning the suggestions from the knowledge base. Second, the knowledge base inside the system performs as the brain of the system. There are numerous knowledge rule bases contained in this part. Each of the knowledge rule bases are coded as IF-THEN-ELSE format in order to make it simple but powerful enough to do its work. When a value of a factor is given, it is transmitted through the knowledge base to find the rule base which responds to that value. The rule base which has responsibility then makes a decision based on the interested value. The decision triggers the suggestion from that rule bases and return the text to the user. Finally, the last part of the system deals with the user by communicating. It acts like the face of the system to ask the question and present the suggestion by the interactive character like a real expert in person. The diagram of the process of the system is shown in Figure 3.3.

In the first phase, the user is asked to give values of primary factors which can be obtainable directly from the document of the project or site investigation. The examples of these documents are building plans, site plans, and specifications. When all of the values are ready, the user can submit them to the system. The system will generate suggestions with codes of associated rule bases.

Next, the system proceeds to another phase, the middle phase. The user is asked to plan along with the suggestion from the system, especially the equipment. The system can display choices that the user can follow through. After user plan according to the choice, the system will go to another suggestion to let the user insert more detail into his layout. The process continues until the planning reach the end of the guideline in the second phase. The layout at this point should have all of components with their properties available on the plan.

Finally, the system reaches the checking stage. The plan from the middle stage might be able to utilize already. However, it might not be safe or productive due to some conflicts. This stage checks the relationship between components and also between the building and components also. The main objective is to eliminate the risk of accidents occurred by the cause of poor site layout and raise the productivity of the work on the site. The user can have his layout checked by the system. Then, the user can improve the layout according to the checking and advising of the system.

The system is developed by the software named Ren’py. Ren’py is an open source and free software. It is based on the python language. Anyway, Ren’py already modifies the code and command to be simple enough for every level programmer. It is usually used to create games based on text and picture which is called visual novel. Anyway, Ren’py can be a powerful software to create numerous application with some modification and imagination. The interface of the software is shown in Figure 6.1. It can store numerous projects inside but the user can choose which project is going to be called conveniently. Ren'py also has a built-in tutorial which can assist the coding and provide some sample codes. These sample codes can be modified and used as a composition of the other applications.

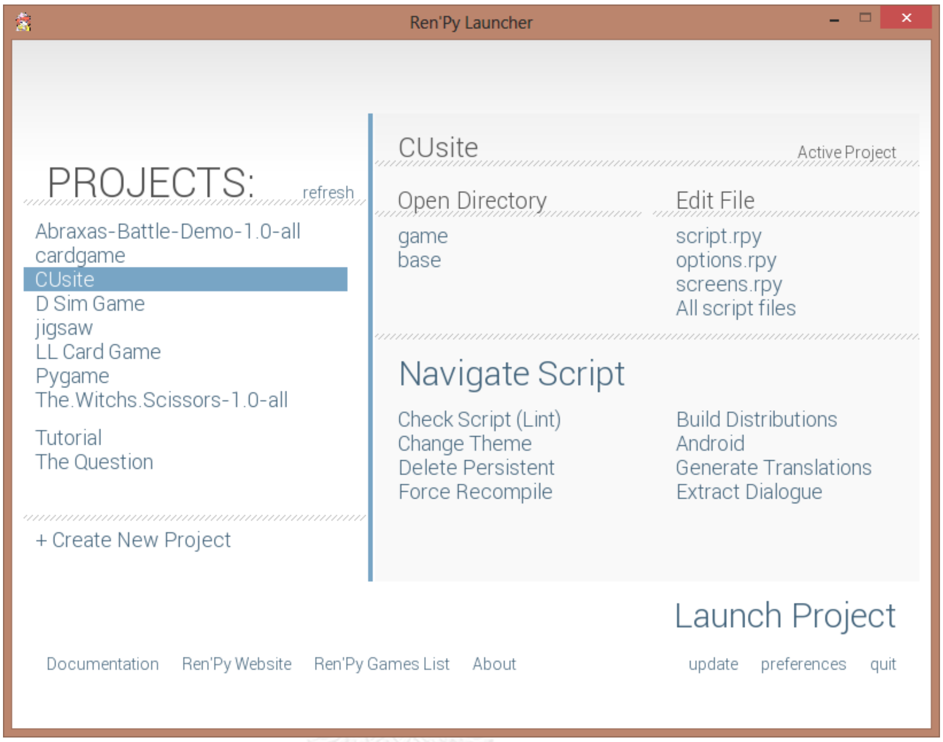
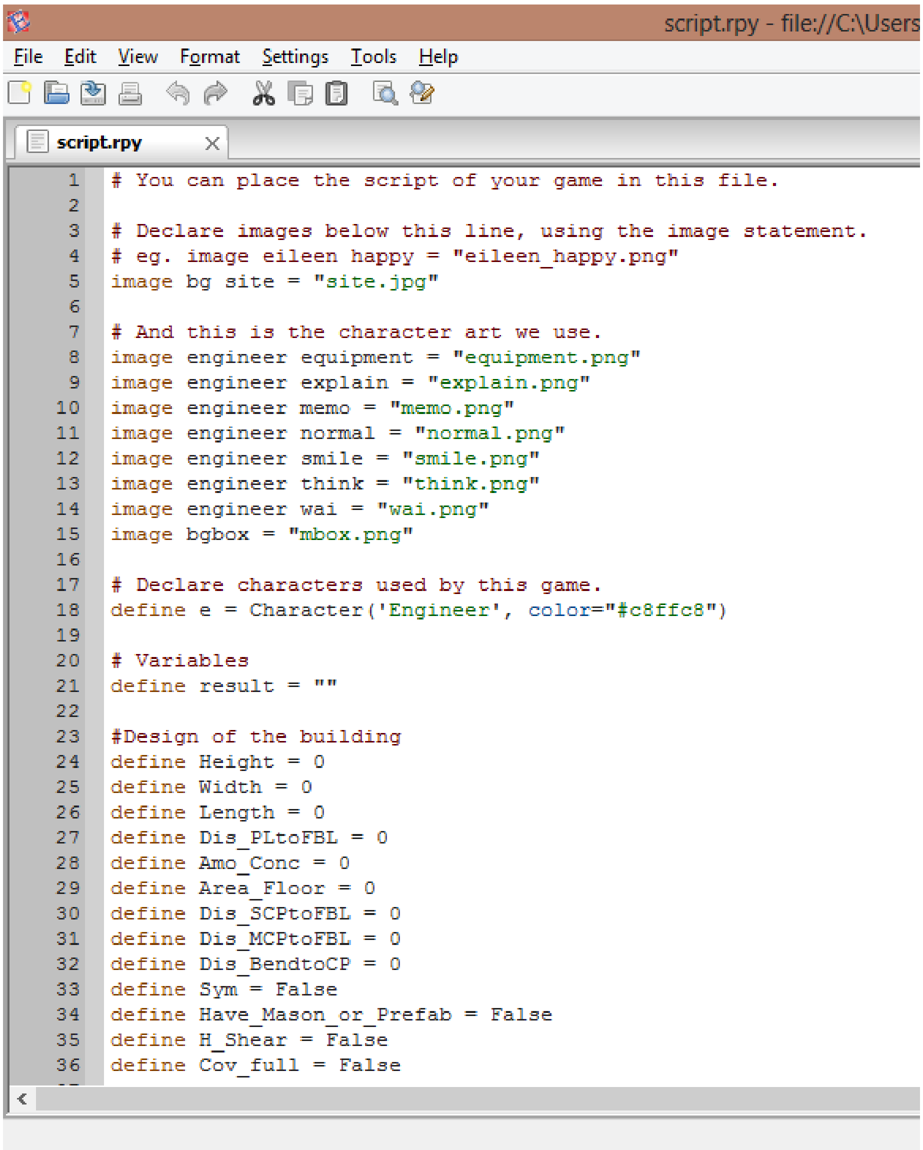


Figure 6.1 Interface of Ren'py

Ren'py has built-in commands asking the user to choose choices and link the user to another screen based on the chosen choice. These functions are the main core of the system. Providing choices or leaving blanks to let the user give the input manually are very crucial to the IF-THEN-ELSE basis for knowledge-based system. Values and choices can trigger the decision making by the coding inside the responded rule base. The suggestion can show up freely inside the text box which does not require the maximum length or number of the alphabet. Moreover, the system can show a character which can act as the medium between the user and the system. The character can question or give suggestion based on the script and reaction from the decision providing, make it to be more user-friendly.

6.3 Process of the system development

The first step of the system development is to define variables. Variables can be announced at any time but pre-defining assists programming to be more convenient when some errors occur. The programmer can trace back to the group of variables to the check where origins of errors are.. Variables in Ren'py can be representative of values of factors, background, sound, and characters inside the application. A character is designed to act as the medium between the user and the system. Variables are separated into categories based on the types of the corresponding factors, for instance, the design of the building, the location of the site, and the availabilities of components. Values of each factor are set at the default value when the system starts. Variables which are integer are set to be zero, while, variables which are Boolean are set at false.



```
# You can place the script of your game in this file.

# Declare images below this line, using the image statement.
# eg. image eileen happy = "eileen_happy.png"
image bg site = "site.jpg"

# And this is the character art we use.
image engineer equipment = "equipment.png"
image engineer explain = "explain.png"
image engineer memo = "memo.png"
image engineer normal = "normal.png"
image engineer smile = "smile.png"
image engineer think = "think.png"
image engineer wai = "wai.png"
image bgbox = "mbox.png"

# Declare characters used by this game.
define e = Character('Engineer', color="#c8ffc8")

# Variables
define result = ""

#Design of the building
define Height = 0
define Width = 0
define Length = 0
define Dis_PLtoFBL = 0
define Amo_Conc = 0
define Area_Floor = 0
define Dis_SCPtoFBL = 0
define Dis_MCPtoFBL = 0
define Dis_BendtoCP = 0
define Sym = False
define Have_Mason_or_Prefab = False
define H_Shear = False
define Cov_full = False
```

Figure 6.2 Example of the variables defining

The second step is to define scenes inside the system, which Ren'py calls these scenes as labels. A label consists of the face of the character, background, sound, conversation dialogues, decision choices, and destinations of each choice. The system can communicate with the user by these conversation dialogues. The character and text can be shown at the same time to imitate the talking. At the end of each label, it is usually finished with the command "menu", This command appoints the system to display choices from the programming. Each choice requires having commands if the interested choice is select. The simplest way to end the label after a choice is chosen is "jump". Jump is a specific keyword used to change the scene of the system. The example of the label is shown in Figure 6.3. Objectives of labels in this study can be separated into three functions. First, a label can be used as an explanation or introduction to the application. Second, it can be utilized to question the user to give inputs or clarification. Finally, it can be assigned rule bases and give suggestion to the user after the compiling. The example of rule bases inside labels is shown in Figure 6.4

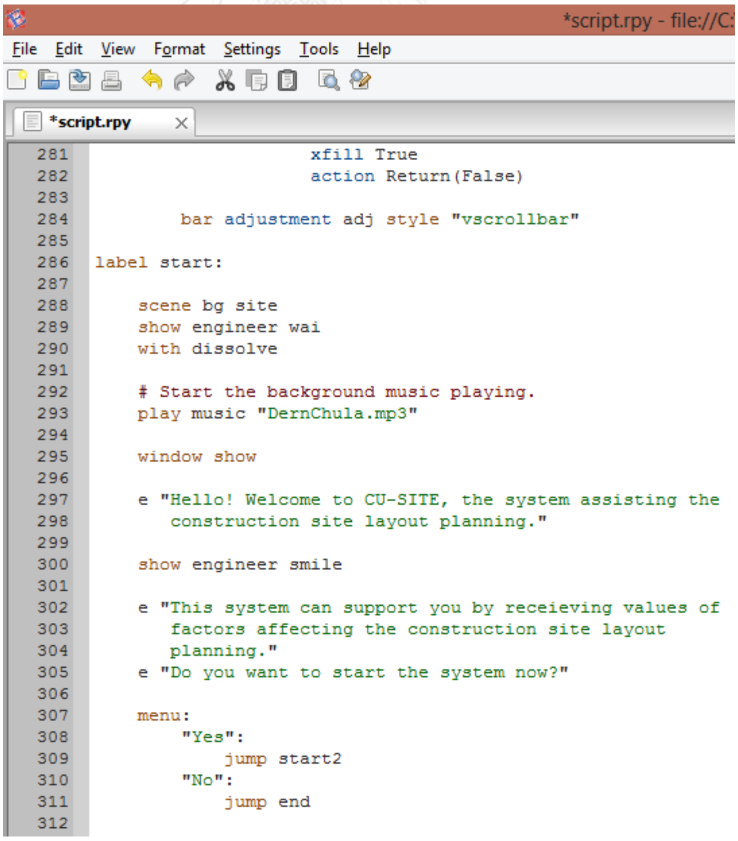


Figure 6.3 Example of label defining

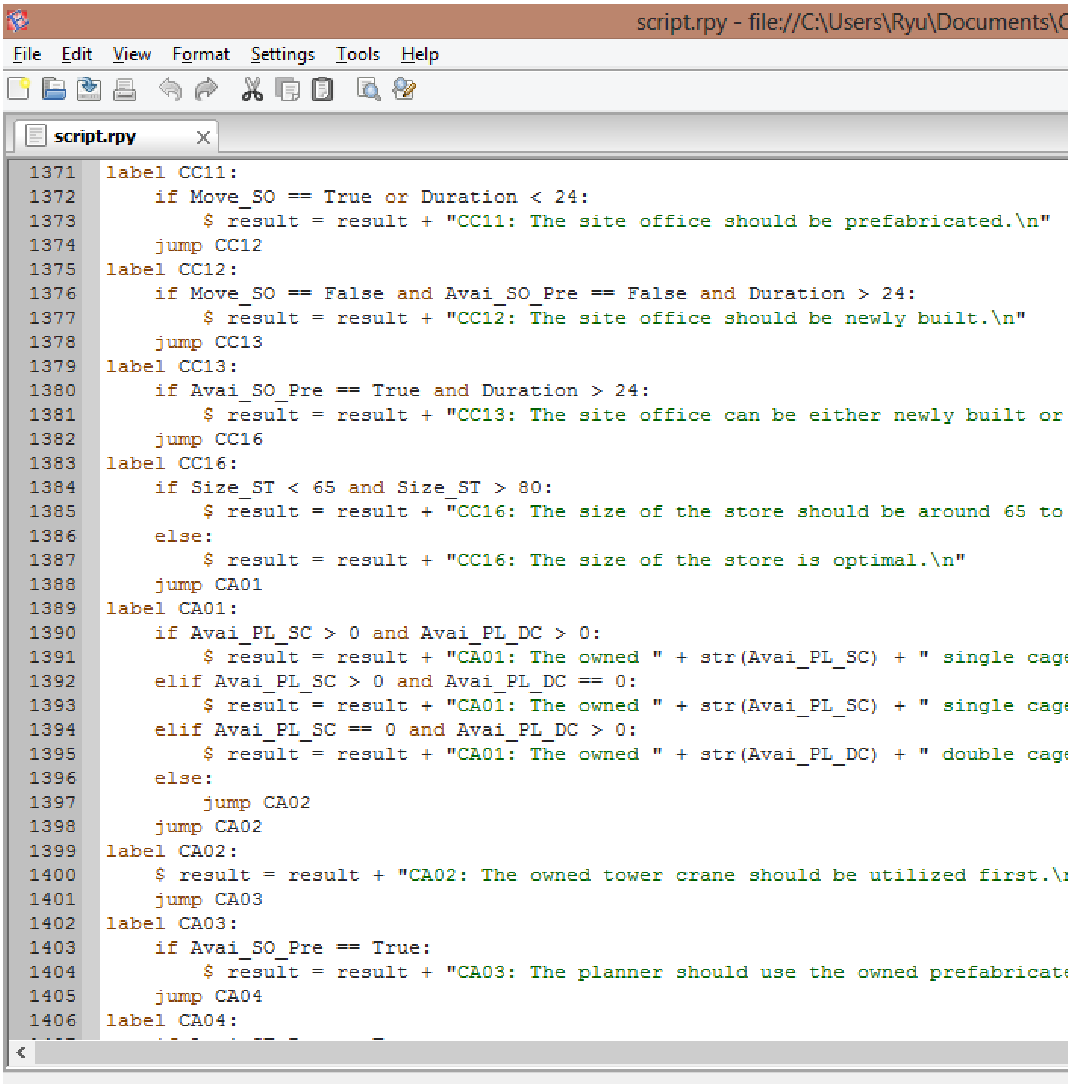


Figure 6.4 Example of rule bases defining

Third, the flow of the program is planned based on the guideline proposed in Chapter five. The flow chart of the system is shown in Figure 6.5. The black colour is the flow of the system separated by the work process. The blue colour indicates documents which are the input and output of the system. The input of the system consists of all relevant data as shown in the guideline, for example, building plans, site plans, specifications, and detail of the project. The initial screen displays as exhibited in Figure 6.6 if the application is called. When the system begins, the introduction is displayed as shown in Figure 6.7. The system will request for values of

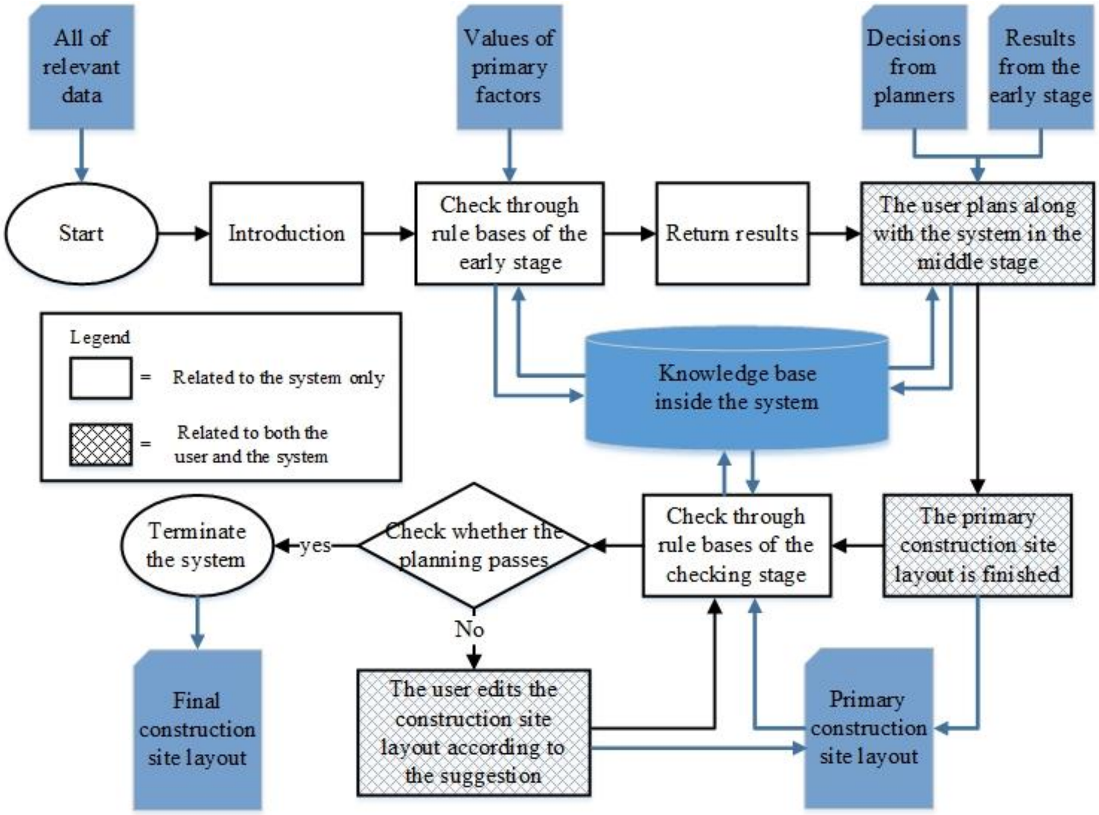


Figure 6.5 Flowchart of the system with input and output.

Figure 6.6 Initial screen of the system

factors which is required by the early stage as seen in Figure 6.8. These factors are separated by their major categories, for instance, the design of the building, the location of the site, and constraints of components as displayed in Figure 6.9. When a category is clicked, the system navigates the user to a list of factors inside the categories. The example of factors inside the design of the building category is exhibited in Figure 6.10. The user can click submit all of values when they are ready. The system transfers these data to the knowledge base and checks through the knowledge rule bases inside for the decision making. The knowledge base returns results and suggestions to the interface of the system along with codes corresponding to the responded rule bases. The example of the result is shown in Figure 6.11. By now, the user will have the information for the overview of the construction site layout. However, for the detailed layout, the planner should go through the middle phase to have precise detail of each component. In the middle phase, the system requires decisions accompany with the result from the early phase. For example, in the case of tower cranes, the system asks the user what type of the installation will be used for a tower crane as displayed in Figure 6.12. The user has to consider for the

Figure 6.7 Introduction to the system

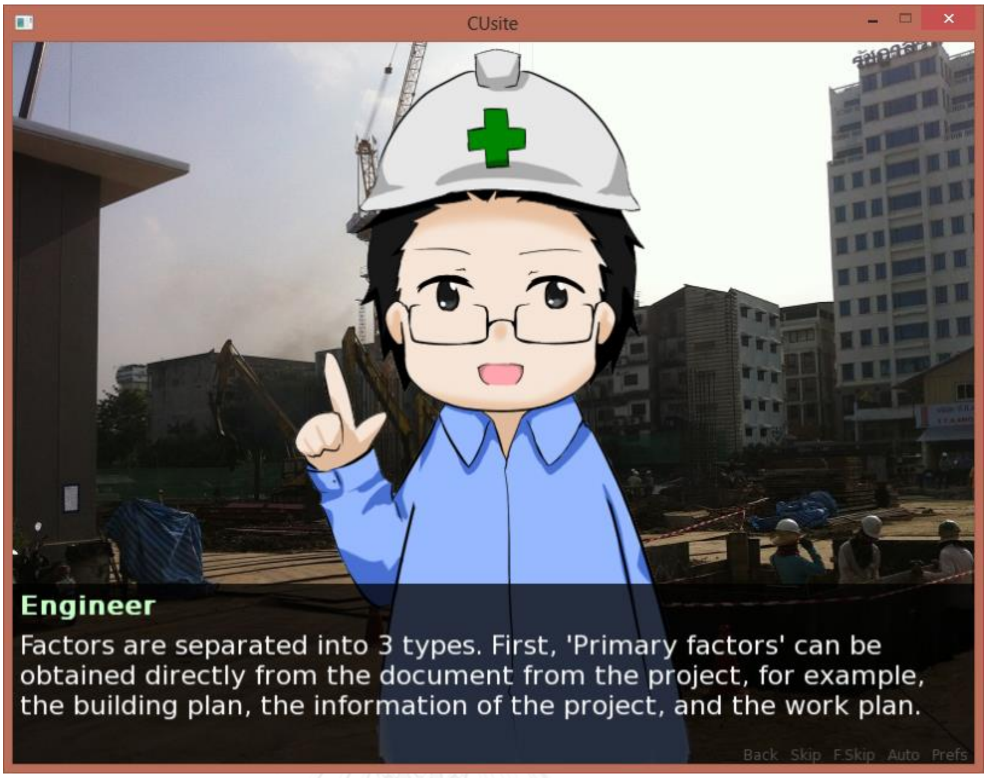


Figure 6.8 Explaining of factors

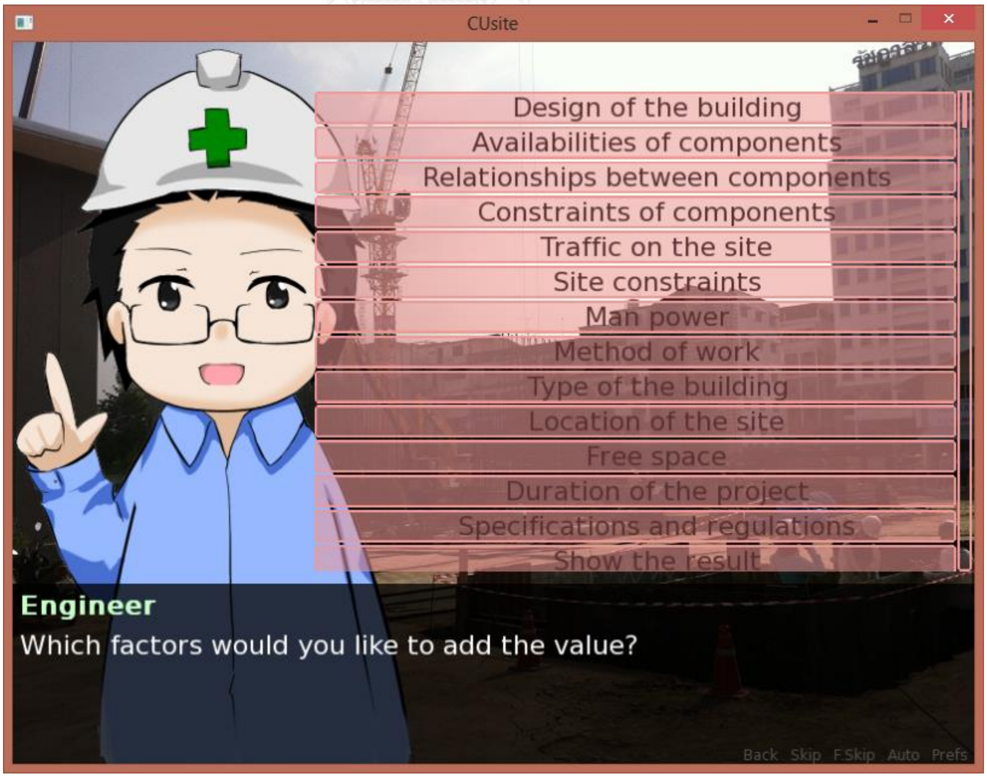


Figure 6.9 Screen shows all of factors, separated by categories

Figure 6.10 Example of factors inside a category

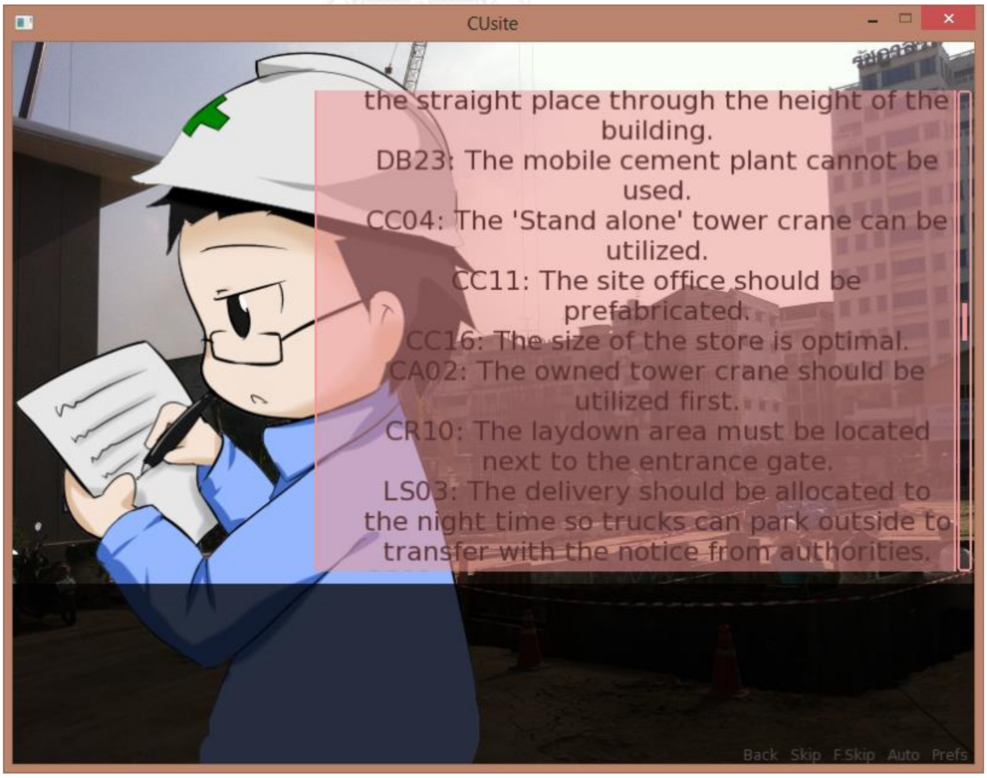


Figure 6.11 Example of the result after the system calculated

Figure 6.12 Example of choices in the middle stage

result from the early phase, for example, the building is taller than thirty metres so a stand alone tower crane cannot be utilized on the site. The user can plan along with the system step by step. The result from this phase is a primary site layout but required some checking to raise the safety level and improve the productivity. The main concern of the last phase, the checking stage, is the relationship between components. This factor is one of the major troubles for CSLP referred from the huge number of sub factors in the chapter five. The coverage of tower cranes is questioned to the user as shown in Figure 6.13. The user can answer by clicking the interested component in Figure 6.14 and clarify whether tower cranes on the primary site layout cover it. The system will check for the suitability and return the warning or approval. After the checking stage is finished, the construction site layout is ready and workable. The users might blend their own knowledge with the one gained from the system. The system only provides the guideline, not the exact method which forces users to follow.

Figure 6.13 Example of question in the checking stage

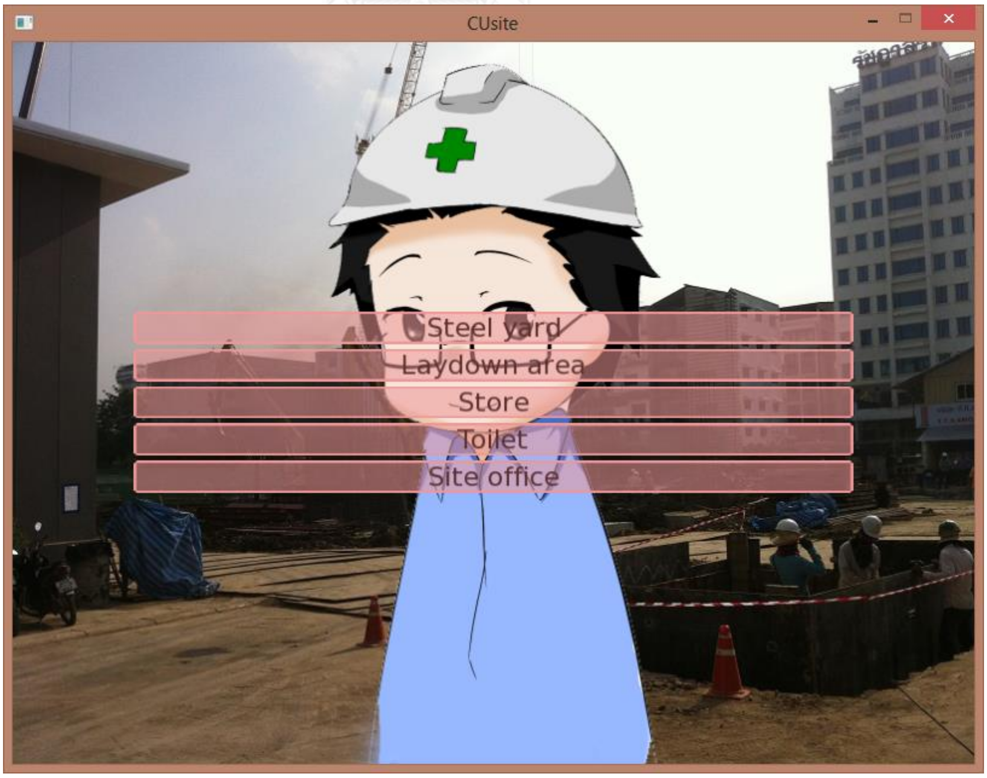


Figure 6.14 Choices in the checking stage

6.4 Conclusion

The development of a system for CSLP is displayed in this chapter. The system is knowledge-based. The core knowledge of the system came from the guideline in Chapter five. The system is developed based on Python computer language by the software named Ren'py. Ren'py is a free and open source program which mainly used to develop visual novel game. However, it is selected to be utilized in this study due to the ability that can apply IF-THEN-ELSE coding powerfully. The application can "jump" from labels to labels through choices that the user chooses. Python computer language in Ren'py has been modified to be simple but still powerful to be used as a research application.

The system separates the work procedure into three phases similar with the guideline proposed. It consists of the early stage, the middle stage, and the checking stage. In the early stage the user is questioned to provide values for factors to let the system generate the suggestion from rule bases in the knowledgebase. The user can get the overview of the construction site layout from this stage. Next, the middle stage furnishes the overview into the primary construction site layout based on the cooperation between the system and the user. The result from the early stage accompanies with the decision making from the user are two main input of the system in this phase. Finally, the checking stage is conducted to raise safety and productivity of the construction site layout. However, the user might adapt his previous experience into the knowledge from the system because the system is only a guideline, not an exact knowledge. The user can blend his knowledge with the knowledge from the guideline to open the possibility to reach more productive construction site layout.

Chapter 7
Case study validation

7.1 Introduction

In order to receive the reliability of the study, a case study is conducted to benchmark the knowledge gained from the study with the real practice. A case is selected out of the five standard cases in order to raise the external validity of the knowledge base. Knowledge rule bases from the study are compared with conditions and principles of the planning of a case study. Moreover, the system is also implemented by low expertise engineers to benchmark between the real planning from the expert and the planning from low expertise engineers with the assisting of the system.

The topics are separated into 13 topics, which are: (1) introduction, (2) basic information of the construction site, (3) CSLP of the project, (4) tower cranes, (5) concrete pumps, (6) passenger lifts, (7) site offices, (8) toilets, (9) stores, (10) steel yard, (11) laydown area, (12) other components, and (13) conclusion.

7.2 Basic information of the construction site

This project is an apartment located in a private area. The building is 55 metres tall with the area of 5,000 sq.m. per floor. Concrete used to construct this building is approximately equal to approximately 35,000 cu.m. The building is constructed with the conventional reinforced concrete design. The wall is made of the prefabricated concrete panel. The shape of the building is a symmetric cross, which has an open core in the centre of the building. The lift cores and stairs cores are located at the central area of the building. The price of the construction project is 3,000 million baht.

The construction site has the area around 20,000 sq.m. Consequently, the free space on the site is 15,000 sq.m. or 75% of the entire area. There are neighbours all around the site except the front gate where is connected to the main road of the owner’s land. The traffic condition around the site is in a good status. However, the traffic outside of the owner’s property is severe due to the bridge construction. Trucks can access the site conveniently. They can be driven around the site like a roundabout with the building located at the epicenter of the roundabout. There is an entrance gate which is used as the main gate of the construction site.

7.3 CSLP of the project and rule bases validation

CSLP of this site starts by specifying the design of the building. The contractor plans the work processes to construct the building. Then, the contractor can know components and materials that are going to be used based on these work processes. The components on this construction site are (1) tower cranes, (2) concrete pumps, (3) passenger lifts, (4) site offices, (5) toilets, (6) stores, (7) steel yard, and (8) laydown area. The work processes also furnish the worker required to finish each job. Therefore, the contractor can know the number of labours they have to hire. The number of labour on this site is around 900 people. The organization chart is also formed in this state. It tells who have to work on this site and what their duties are. It is the main document for the designing of the site office. In this project, the organization chart also provides the phone number for a convenient contact inside the party. The picture of the organization chart is shown in Figure 6.1.

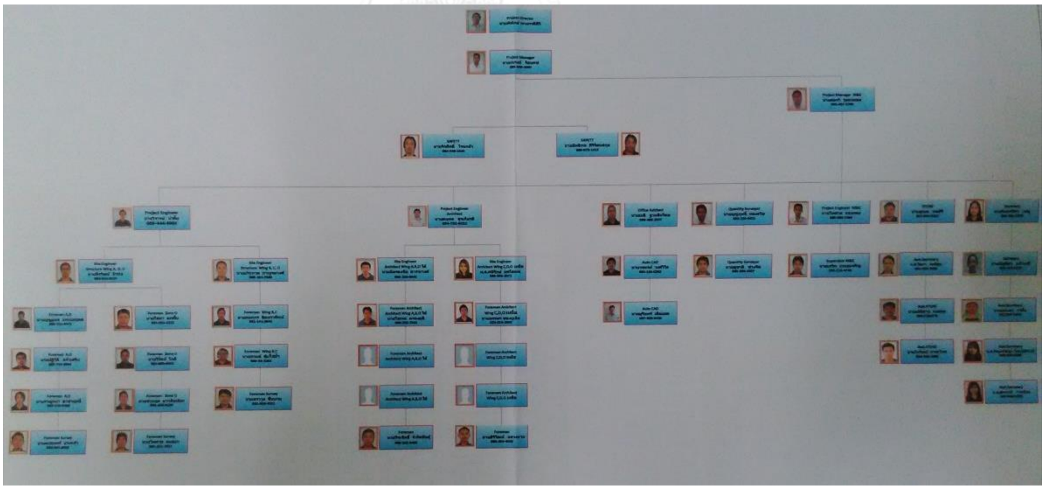


Figure 7.1 Organization chart on the site

Specifications and regulations have to be fulfilled or followed. The owner is very strict with the safety and environmental issues due to the location of the site, where it is settled inside the owner’s land. For the mobile cement plant, the main obstacles rejecting the usage on the site are the specification from the owner [SR06] and the interest of the supplier [SR07]. The owner specifies numerous constraints if the contractor would like to have the plant on the site, for example, the noise and dust has to be protected and the traffic inside the owner’s property has to be well prepared. The supplier lacks their interest after knowing the specification from the owner. However, they have another plant where can support the delivering although it does not be placed on the site.

The building plan is necessary for the equipment planning and materials purchasing. The construction requires the support from tower cranes to deliver the material to the work space. Therefore, tower cranes should cover all of the building due to the high-rise building nature. There are no equipment except tower cranes which can support the work at 55 metres from the ground [DB05]. Other than delivering, tower cranes can also assist the installation of walls and remove the formwork. The concrete pump is also essential to raise the productivity of the concrete pouring. The smoothness of the pouring plays a vital role for the quality of the concrete. Therefore, using the concrete pump can answer the question greatly for the long pouring like foundations and floors. However, in order to achieve that quality, the concrete pump needs constant support from concrete trucks. Consequently, two concrete trucks can wait on this site in the prepared area where does not obstruct other works [FS09]. Passenger lifts are also planned to be utilized on the site when the construction progresses. Ladders are placed instead in the first phase of the construction.

The site visiting is crucial for the designing of the site plan. The environment nearby from the building plan cannot be told from only the building plan. The site visiting can also assist the planner for the boundary specification of the site in case of the owner does not indicate the boundary for the site plan. Then, the requesting for the right of the land can be proposed to the owner. The planner can get the overview of the construction site by the finalization of the site plan, for example, the location of components, the traffic on the site, and the material handling. The environment around the site in this case is small housing habitats which require the environment friendly construction site. Therefore, the dust and sound should be controlled and the safety should be concerned.

Figure 7.2 Clean work area and the protection

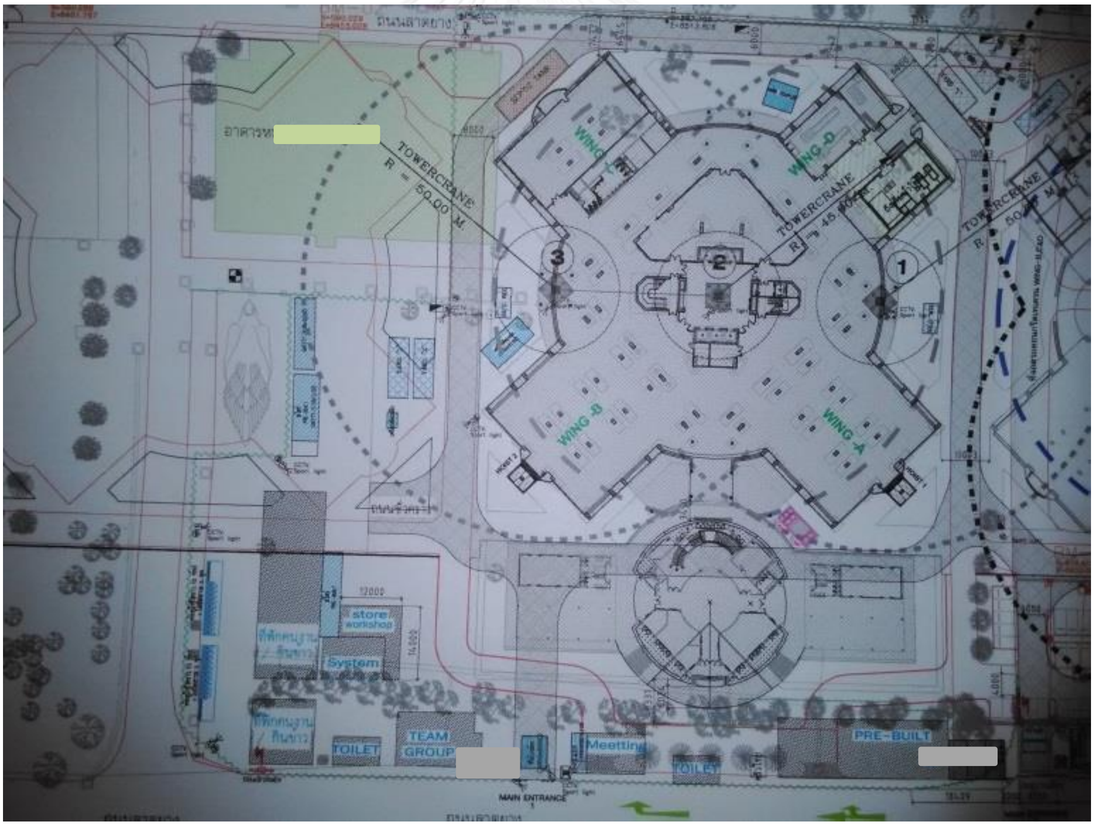


Figure 7.3 Plan of the construction site

In order to precisely illustrate the facts on the site and clearly compare them to the knowledge rule bases, topics are separated into each component on the site.

7.3.1 **Tower cranes**

There are 3 tower cranes on this site in order to cover all of the building and storages [DB05]. They are all placed in the symmetrical positions like the building [DB06]. They are attached to the building [CC02 and CC05]. Two of tower cranes are attached to the side of the building, while another one is located inside the central open gap of the building [CC01]. The outside tower cranes attached to the prefabricated concrete panel wall [DB01 and DB03]. All of these tower cranes are installed at the place where their masts can go through the vertical axis [DB07]. The planner explained that the tower crane is optimally attached to the building with around 50 metres. It does not require the lifting frequently due to the long span of its mast. On the other hand, if it is installed in the core, it will cost at least a day for the lifting. Consequently, it can work at it full performance for a long time until it has to be lifted again. Two tower cranes outside have fixed jibs because they can deliver the material faster than the luffing jib, they are also stronger, and they can rotate without obstruction [CC06]. However, the central one has a luffing jib because it does not require carrying material like the outside ones. Its duty is to support the work inside the building. Moreover, it has to be aware of the masts nearby which using the luffing jib can avoid the collision better [LS09]. These tower cranes are placed not further than 6 metres from the building [CC09] and the radius are 45 and 50 metres which are the standard radiuses [CC10]. The planner also calculates the capacity at each distance of the tower crane's jib to check that it can carry the material with safety [CC10]. The tower crane cannot rotate outside of the construction site due to the safety aspect with the owner's people who live near the construction site [SR03]. Finally, the central tower crane is supported from outside tower cranes when it has to be removed [MW01]. This implementation can save the cost of installing the derrick crane to uninstall the tower crane inside a building.

7.3.2 Concrete pumps

The concrete pump can raise the productivity of the concrete pouring. There are no technologies in the commercial stage that can deliver 35,000 cu.m. of concrete constantly and rapidly like the concrete pump. The planner plans 2 stationary concrete pumps to be used and place at each site equally due to the symmetrical shape of the building. The concrete pipes are attached to the building at the central open gap side which is masonry walls [DB12 and DB14]. There are no bends before they reach the vertical bends [CC18] and they do not exceed 30 metres from pumps [DB15]. The furthest distance which the concrete pump has to service is less than 50 metres after they vertically bent also [DB19].

Figure 7.4 Nearby environment of the construction site

Figure 7.5 All of tower cranes on the site

7.3.3 Passenger lifts

The planner designs to place 2 double cages passenger lifts at the symmetrical positions. The total of 4 passenger lifts is the same answer with the formula gained from the study (900 labours in total, 200 labours per passenger lifts) [DB17]. The rails of passenger lifts are installed at an area where will be furnished with prefabricated walls [DB18 and DB20]. The panels which the rails pass can be finished when passenger lifts are removed. The furthest distance where the labour has to reach from the passenger lifts' location is 80 metres. This amount does not exceed 100 metres from the study which is acceptable [DB21]. Passenger lifts start the operating on the first floor because they have to assist the material delivery as well [MW05]. The areas around the passenger lifts are prohibited from passing due to the safety aspect [SC08]. If anyone violates the restriction and has accident, the insurance to remedy the injury is not paid. The toilet is also located far away from the passenger lifts [CR04].

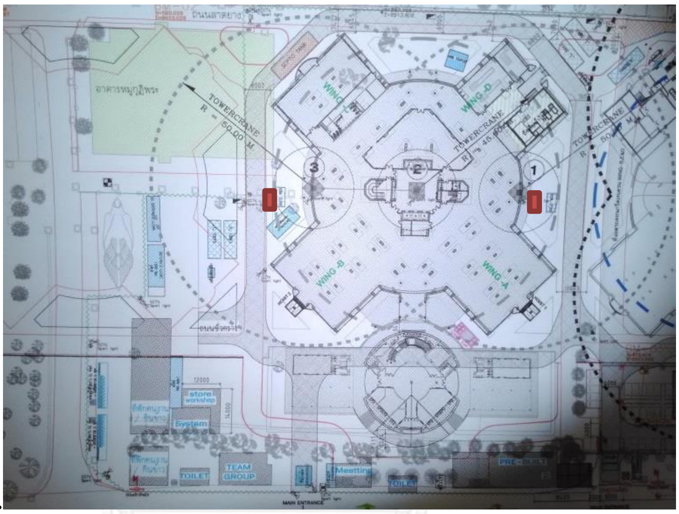


Figure 7.6 Locations of concrete pumps on the site

Figure 7.7 Double cages passenger lifts on the site

7.3.4 Site offices

The site office in this construction project is newly built due to the enormous free space (15,000 sq.m. and 75% from the total space) and the duration of the project is longer than 2 years [CC11 and FS07]. The material used to construct the site office came from the stock of the contractor [CA03]. The main material of the site office has heat resistance and can be recycled. The planner insisted that using the traditional plywood can be a waste of money because it is hard to remove without destroying. The as built plan of the site office is shown in Figure 6.8. The planner designs the site office to be a place where everyone on the site can work conveniently. Therefore, the planner decided to use a huge public area in the site office which allows the staff to do activities together, for instance, the dining area, the meeting, and the table tennis section. These activities can form unity in the staff party. The workspace for each director is 5 sq.m., while for the staff are 2 sq.m [MP01]. There are 3 directors and 43 staff who have seats in the site office. The total area of the workspace is 101 sq.m. However, the total area of the site office is 360 sq.m., which means the site office is more enormous than normal for 2.5 times it should be due to the planner's policy. Nevertheless, the planner accepts that it is worthy because it can raise the morality of the parties and the productivity of the work. The site office is located in front of the site because it is convenient for the visitor to access [SC03] and that place will be a garden where can be the last place to be redecorated [SC04]. The site office is located outside the coverage of tower cranes for the safety aspect [SC02].

Figure 7.8 Material used to construct the site office

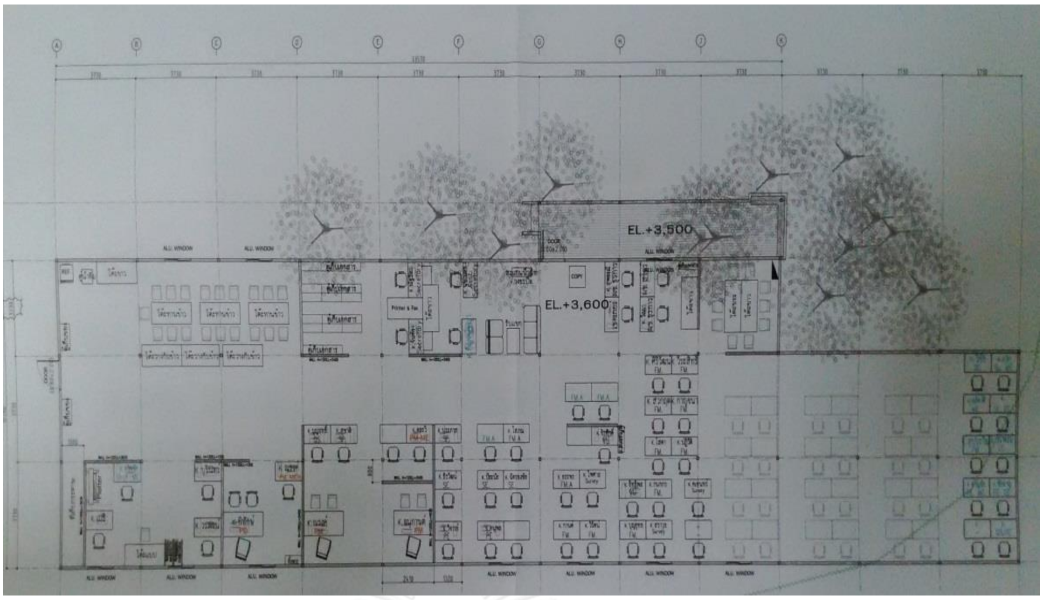


Figure 7.9 As-built drawing of the site office

Figure 7.10 Public area where the staff can do activities together

7.3.5 Toilets

The toilet is designed based on the labour legislation [SR02]. Nine hundreds labours have twenty rooms of toilet, while one hundred staff from the contractor and the consultant have twelve rooms of toilets. These toilets are separated from each other [CC14]. The restroom for labours is approximately 4 sq.m. per room. It exceeds the minimum in the regulation which limits at 1.5 sq.m. per room. The area of 4 sq.m.

per room is also in the average space that the study proposes [CC14]. Toilets are located at the corner of the construction site which the visitor cannot see them clearly [FS05]. They are placed outside of the tower cranes' coverage like the site office [SC05] and does not have people walk pass there outside [LS07]. Moreover, the labour toilets are settled near the man hole outside of the construction site for the sanitary purpose [LS04].

Figure 7.11 Labour toilets on the site

Figure 7.12 Staff toilets on the site

7.3.6 Stores

The area of the store in this construction site is 65 sq.m., which is in the range purposed by the study (65-80 sq.m.) [CC16]. Trucks cannot access the store; however, pick-up trucks can [TS09]. The newly built store is constructed by the recycled material as same as the site office [CA04]. The store does not have to be moved inside the building due to the enormous size of the free space [FS06].

Figure 7.13 Store on the site

7.3.7 Steel yard

A single supplier supplies the steel for this construction site site. Then, when the contractor needs to stock the reinforcement steel again, the supplier will deliver it to the site after a phone call is made [FS02]. The delivery trucks can access the steel yard conveniently [TS06]. From the formula purposed in the study, the steel yard on this construction project should be around 950 sq.m [FS03]. However, it is only 500 sq.m. on the real job site. The main reason making this difference can be the free space which is greater than normal and let the planner freely design it. The steel yard can get the support from the left tower crane of the construction site whenever the structural work takes place [CR05].

Figure 7.14 Steel yard on the site

7.3.8 Laydown area

The policy of the planner does not want to have stocks left on the field. However, there should be some stock saved up practically, for example, bricks, cement bags, and formworks, in case of there are some errors with the work procedure or delivery. The laydown area is specified at 2 locations. First, the formworks which are not utilized are placed at the field next to the entrance gate and in front of the contractor site office. Second, the materials are stocked at the back part of the site where trucks can access [TS07] and tower cranes can give the assist for the delivery [CR06].

Figure 7.15 Laydown area on the site

7.3.9 Other components

As mentioned in the previous topics, the construction site is located inside the owner's community. Consequently, the owner put numerous specifications about the environment, for example, dust and the road's cleanliness. The planner responds to the dust issue with the mash sheets covered all over the constructing building. These mash sheets can prevent the dust from going outside of the building [SR08]. Although the planner accepts that they might cost huge amount of expense to invest in these sheets, they are durable, fire proof, and recyclable which can share the charge with numerous projects in the future. Except than the mash sheet, the planner also installs the protection from falling debris and accidents. This protection can slide up follows the progress of the construction.

Figure 7.16 Mash sheets and the falling objects protection

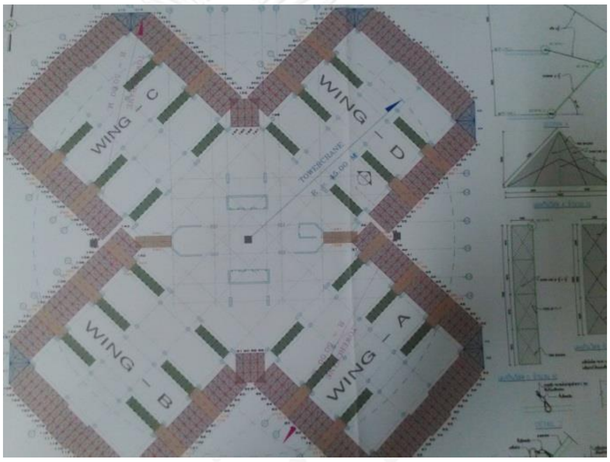


Figure 7.17 As-built plan for the protection installation

The cleanliness of the road is also concerned by many parties, included the district or province administration also. The construction site which does not follow the regulation can be fined from dirtying the road. The planner prevents this penalty by installing the truck’s tires washing yard. It can clean tires by the water jet before the truck goes outside. The washed trucks can go out of the site without dirtying the owner’s road.

Figure 7.18 Washing yard for tires of trucks on the site

The planner would like to have the mobile cement plant on the site due to the huge amount of free space, poor traffic condition, and the amount of the concrete is feasible. Having the plant inside the site can decrease the cost of the transportation for the concrete and grants flexibility on the planner's concrete pouring schedule. However, it is rejected by the concrete supplier because the specifications from the owner are too strict and they have a plant located near the site already as mentioned above.

Finally, one of the special principles of this construction site is the planning for the dining area for labours. It can be seen from the appendix A that numerous experts would like to have a dining area on their sites. However, there are no construction sites where they have an actual dining area on the site yet. Every expert knows the advantages of the dining area for labours on the site but no one takes action about it. The planner explains preferences of the dining area that it can be more than just a place to have lunch together. It can raise the sanitary condition on the site because the trash from the meal can be collected and managed easily. Moreover, the dining area can be utilized as an auditorium to announce news and notification to the whole labour party. Furthermore, the contractor can turn on the TV or projectors to show the safety work principles while labours are having lunch. The planner encourages other experts to plan for the dining area on the site although it does not affect the construction productivity primarily, based on advantages mentioned above.

Figure 7.19 Dining area on the site

7.4 Summary of rule bases validation

In summary, all of the rule bases are verified with the external case study and found that the knowledge rule bases are acceptable. The results are shown in Table 7.1. From 111 knowledge rule bases in the system, if it has to be implemented with the planning of this site, there are 55 rule bases that are triggered by the condition of the site. The majority of the responded rule bases return the same principles and suggestions with the planning on the external case study. However, there are 3 rule bases which the work procedure is terminated. These rule bases relate to the calculating method for the size of the site office, the laydown area, and the steel yard. Values from the system are smaller than what have been implemented on the site. The reasons behind the difference are explained.

(1) For the case of the site office, the planner said that he considered having more space in the site office so he can make a public area where everyone in the office can participate activities together, for example, having lunch, meeting, and play sports.

(2) For the case of storages, the formulas used to calculate for the size are only guidelines for the planner. They give only approximate sizes based on the site area which the planner might plan them to be greater or smaller than the system provides.

Although there are some errors with the external case study, the majority of the knowledge rule bases go along with the real practice. However, they are not severe errors which have to reject the rule bases. The main reason alternates the solution is the size of components which can be differed based on the planner. It can be seen in the summed indices that five experts also cannot meet the exact same size of every component. Therefore, it can be some slight difference using the rule bases which has to be noted.

Table 7.1 Result of the rule bases validation separated by categories of factors

Factors	All	Follow	Miss
Availabilities of components	5	2	0
Constraints of components	19	10	0
Relationships between components	10	3	0
Design of the building	23	13	0
Free space	9	6	0
Location of the site	9	3	0
Man power	2	1	1
Method of work	6	2	0
Site constraints	8	5	2
Specification and regulations	8	4	0
Type of the building	9	3	0
Duration of the project	3	0	0
Total	**111**	**52**	**3**

7.5 System validation

A case study is selected to check whether it can answer the objective that it can assist CSLP for low expertise engineers. Case B is chosen due to the available of free space which can allow the planning to be independent. However, it still has some major constraints that force the planning to head to the same direction. Consequently, it can indicate the similarities and differences between cases clearly.

Two low expertise engineers are requested to do CSLP for Case B with the assistance of the system. The finished layouts then compared with cases which experts have already done the planning in the multiple case study.

Results from the validation are shown in Figure 7.20 and Figure 7.21. It is observed that the main concept of CSLP is similar between layouts of low expertise engineers and experts. The tower crane has to cover majority of the building, the laydown area and the steel yard. On the other hand, its coverage should not cover the site office and the toilet or at least the material path should not pass over these facilities. Moreover, considering the position of components, the positions of components from low expertise engineers usually share the same position with at least one of the layouts from experts. This is a good step for introducing CSLP for new enginners. It can be examined that with the assistance of the system, low expertise engineers who know little about CSLP can also do the job and receive a workable site layout.

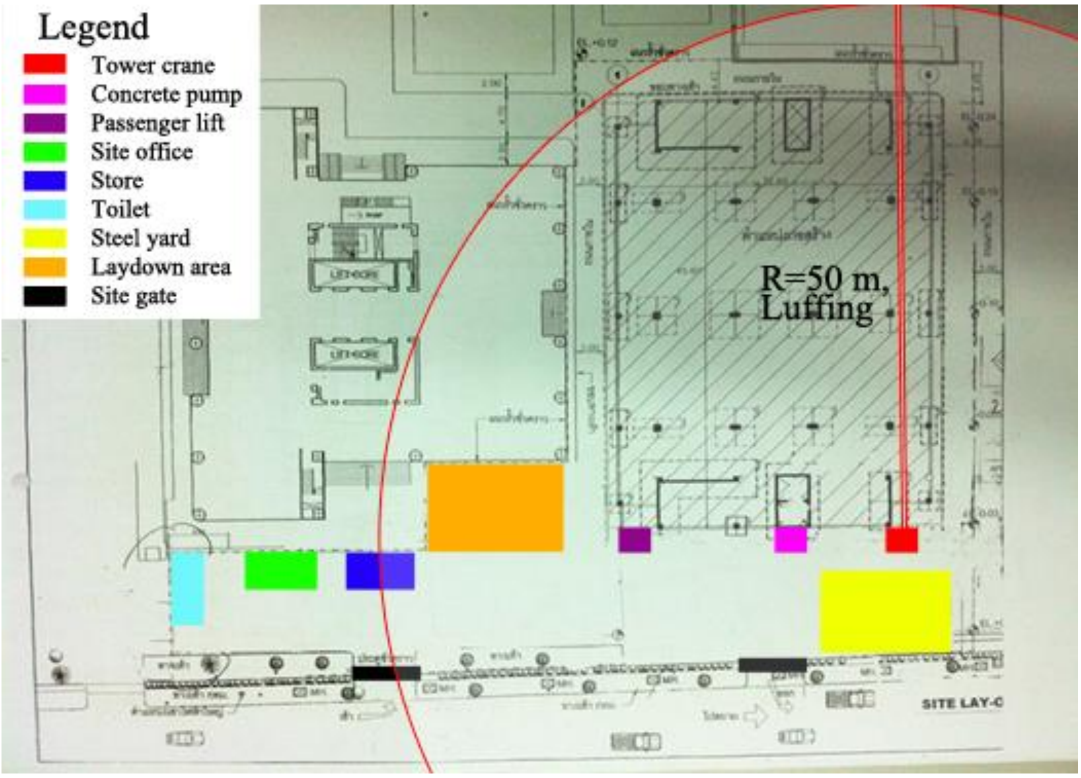


Figure 7.20 Layouts from low expertise engineer 1

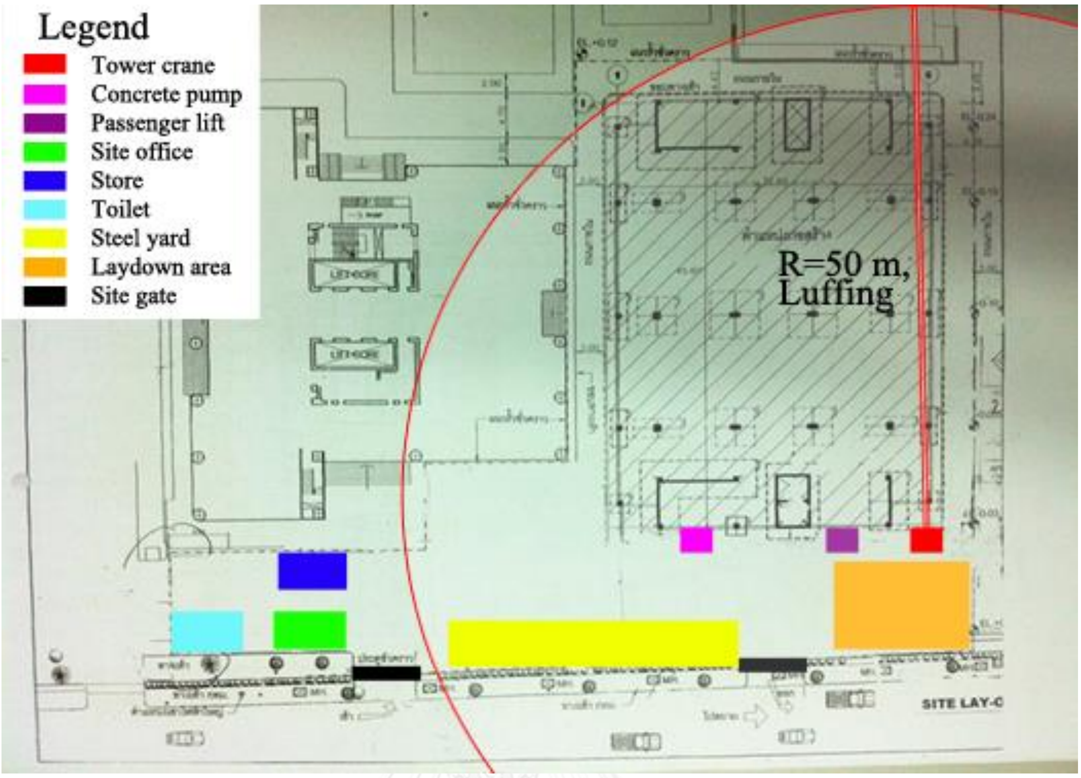


Figure 7.21 Layouts from low expertise engineer 2

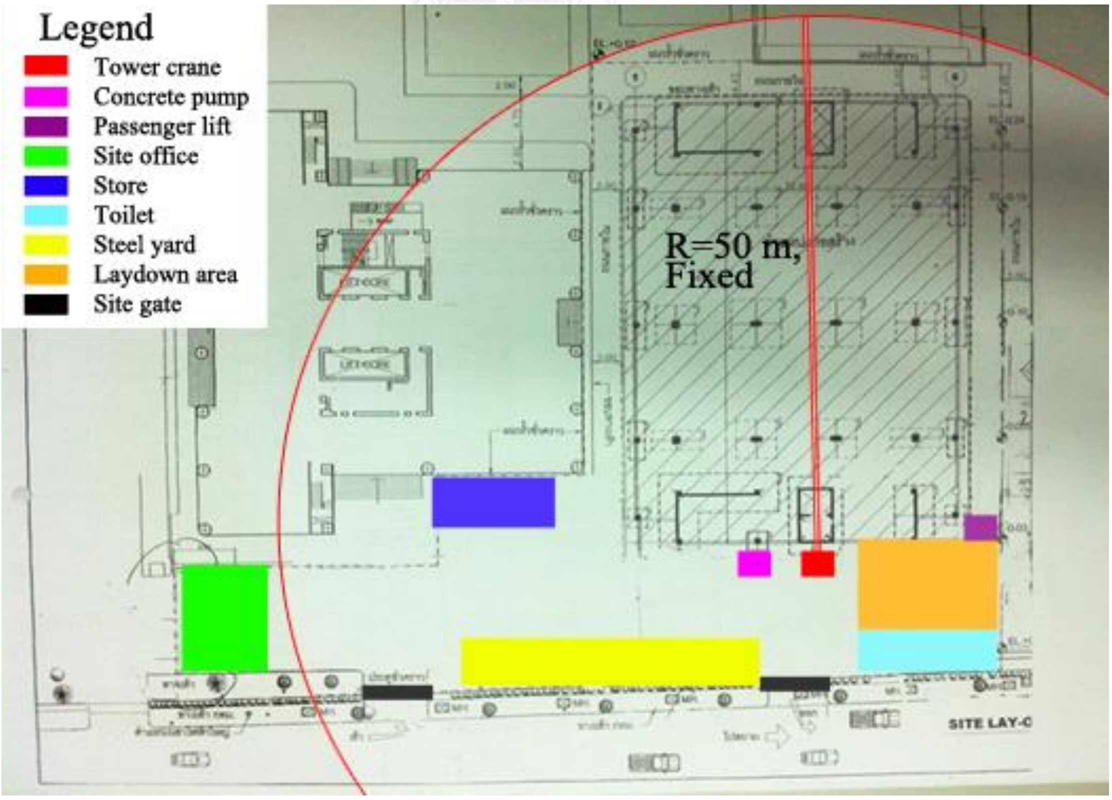


Figure 7.22 Layouts from expert 1

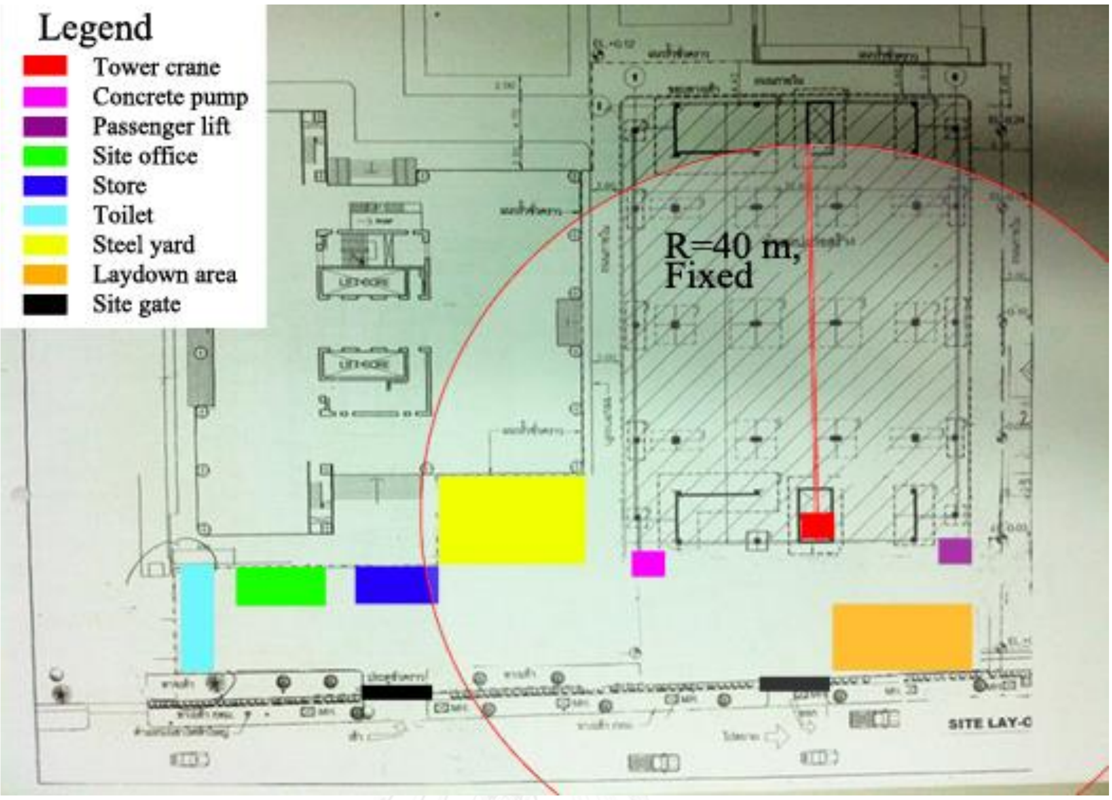


Figure 7.23 Layouts from expert 2

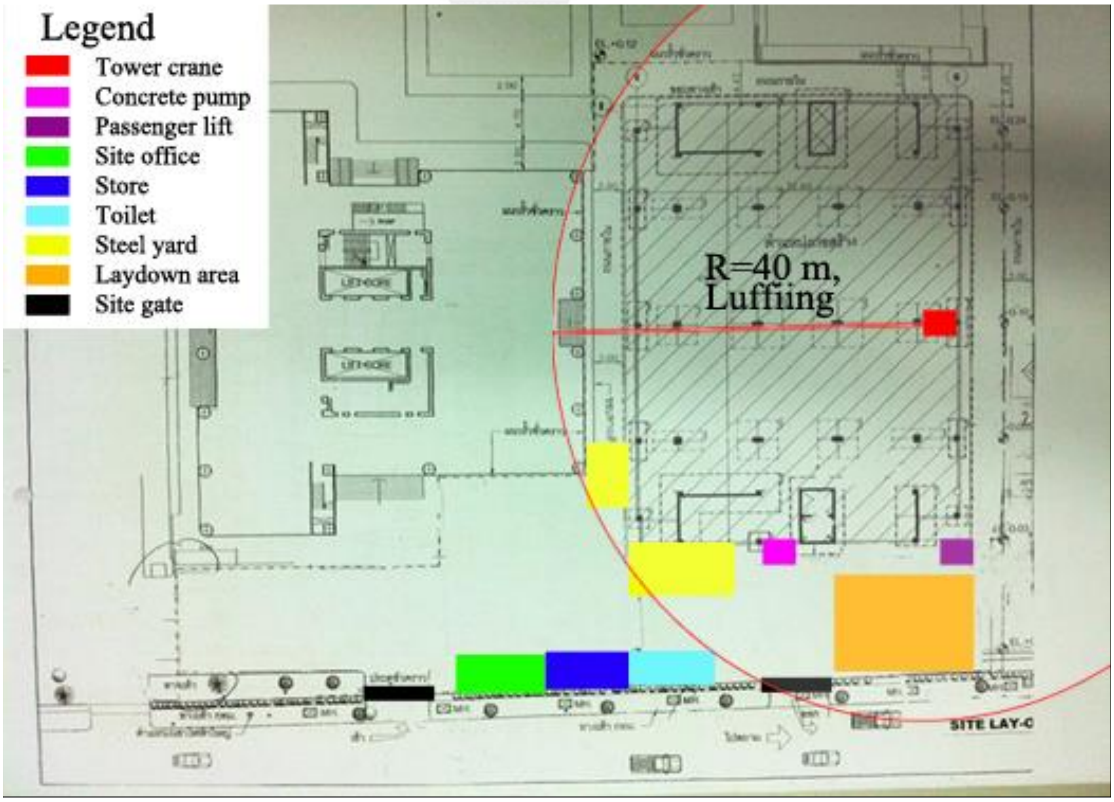


Figure 7.24 Layouts from expert 3

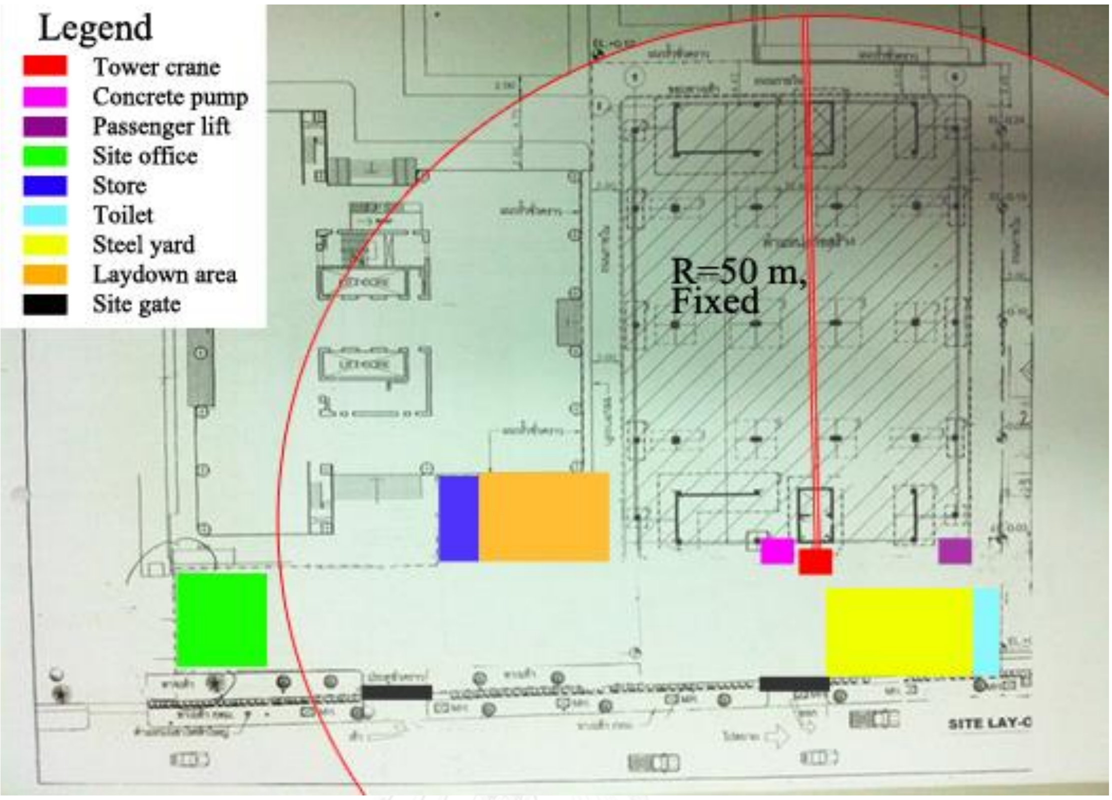


Figure 7.25 Layouts from expert 4

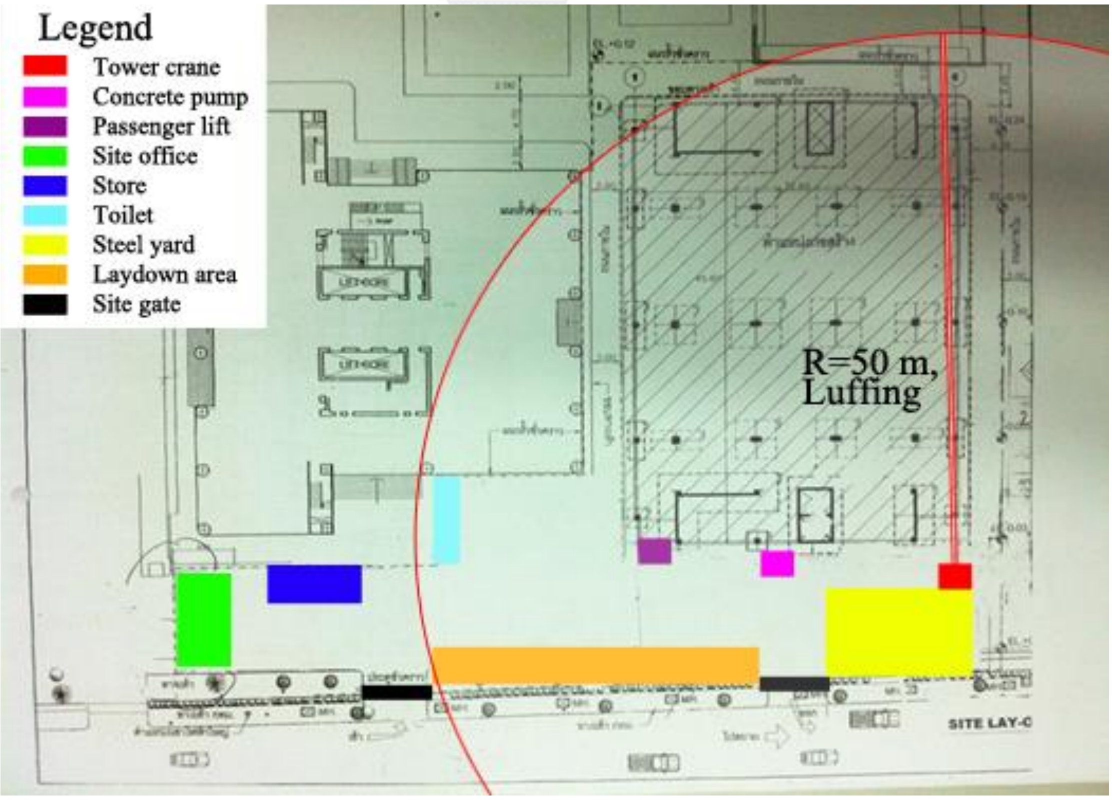


Figure 7.26 Layouts from expert 5

7.6 Conclusion

The question about the reliability of the qualitative data is usually raised. In order to gain the reliability of the findings, the implementation with other case studies can be used as a tool to check. If the same phenomenon leads to the same result, the finding can be specified as reliable data. In this chapter, a case study is selected and observed whether it has the planning principles as same as research findings. Interviews with the expert and the site investigation are conducted. The procedures treating CSLP from the case study are compared. The results show that majority of the principles from the case study can go along with the findings from the study. Thus, the findings gain the reliability and are ready to be utilized with other future construction projects.

Moreover, the system is also validated by requesting low expertise engineers to do CSLP with the assistance of the system. Then, the comparison between layouts from low expertise engineers and layouts from experts is conducted to analyze the similarities and differences between cases. The result shows that numerous principles from layouts of low expertise engineers are similar to the layouts of experts. At least one expert has planned by the same principle with the low expertise engineer for each aspect. The system is proofed that the low expertise engineers can also furnish the workable CSLP with the assistance from the system.

Chapter 8
Research Conclusion

8.1 Conclusion

CSLP is a crucial work in the first phase of the construction project. It can determine the profit or loss of the project. The good construction site layout can raise productivity and safety of the construction site. However, CSLP is usually ignored by the site practitioners. They believe that all of the problems with CSLP can be solved by itself when the construction progresses. The work procedure to manage CSLP is also in doubt. Numerous engineers treat CSLP by “First-come-first-serve” method which does not produce practical knowledge and cause problems to be occurred.

Due to numerous factors affecting CSLP, the planners have to consider diverse aspects in order to achieve the optimal construction site layout. For example, the method of work can affect the location of the tower crane, the site office has to be allocated due to the safety issues, and the laydown area has to be placed in front of the site because of the transportation problems and site constraints. A sole planner might not be able to capture all of the factors affecting CSLP and can lead to accidents and unproductive construction site. In order to reach the optimal CSLP, knowledge and expertise are two important aspects which the planners should have. However, these two attributes cannot be developed by just a small amount of time.

Moreover, there is a shortage for the standard of CSLP. This issue affects planners to be confused about the implementation of the planning. They cannot know whether their construction site layouts are well organized. Although there are no problems occur, it does not mean that construction site layout is suitable and cannot be improved.

From all of the limitations mentioned, factors affecting CSLP are proposed in order to show the detail the planner has to know before the working. The guideline that transformed from these factors is also displayed. It can provide benefit to both the low and high expertise planners. The low expertise planners can check factors affecting the planning first and then follow the guideline. They can realize where to start the planning and understand the reasons behind each decision they should make. The high expertise planners can use the guideline as a benchmarking tool to investigate their existing construction sites for the possible improvement to be made.

CSLP is a complex problem by its nature. It relates to numerous variables and factors affecting the planning. In order to reach the final knowledge for the guideline of CSLP, a systematic data collection and analysis have to be well planned. In this study, the multiple case study method is selected to be the data collection together with the exploratory interview. The multiple case study is a powerful qualitative data collection to gain the in-depth information from the real life circumstances. It is suitable for the investigation to extract the answers from "Why" and "How" questions. It can also work well with the phenomenon that the researcher cannot manage or has little relationship with. Furthermore, it eliminates the fatal weak point of the case study method which relies on only a case. By implementing multiple case study method, it can raise the generalization of the research by increasing the number of cases which can provide more reliability to the research. Another advantage from the multiple case study is the indication of the similarities and differences when the results from cases are comparing. These contrasts and resemblances can furnish the trends for the researcher. These trends can be analysed to find the factors and knowledge behind the decision makings of every expert.

The case selection plays a vital role in the multiple case study because all of the theories and knowledge come from these cases. Each case should have both unique and similar components to let factors be able to be discovered by the management from the experts and the analysis of the researcher. In this study, five cases are selected due to their intervention between the contrasts and resemblances. Moreover, each case should have at least a unique attribute to be able to justify the difference which is going to be occurred from other cases.

Qualitative data analysis is based on three processes. First, the data reduction has to be done highlight important information. Due to the qualitative research nature, the data from the collection is usually formatted in texts more than numbers. By reducing the data means the higher probability to find the interesting findings. Second, the data displaying has to be conducted to present the trends of the information. From the literature review, it can be concluded that the data displaying can influence the quality of the findings. There are various types of data displaying, for instance, charts, tables, indices, and flows. Last but not least, the conclusion drawing is compiled to form the theories or new knowledge from the study. However, as mentioned earlier, the conclusion drawing may not be the last step of the analysis. Sometimes, it might be discovered that the conclusion is not clear enough to reach the finish line of the study. If this situation happens, the process of the study has to go back to the data reduction, data displaying, or maybe the data collection again to clarify the vagueness.

In this study, the tabular method is utilized with the multiple case study to display the similarities and differences between cases. The tabular method is a powerful principle which can show the properties of each variable in each case and lead to the more convenient analysis. The attributes used to justify the properties of each variable on the construction site come from the clustering and counting method from the exploratory interview in the first step of the study.

The summed indices from the data processing method is analysed based on the differences and similarities of each variable's properties. The result from analysing is the facts behind the decision making. These facts are sent back to the expert panel to gain the approval and correction raising the validity of the result. The factors affecting CSLP are revealed from their effects with rule bases and presented to let planners know which data they should prepare before the planning. It can reduce problems that can occur from the lack of data. Both components from the exploratory interview and the multiple case study are compared to form the data triangulation of the study. The similarities and differences from these two methods are also presented for further analysis. It is revealed that the data from these two sources head for the same direction which is reliable.

There are thirteen main factors that affect the construction site layout, which are the design of the building, constraints of components, relationships between components, the method of work, the location of the site, site constraints, specifications and regulations, the traffic on the site, the amount of free space on the site, the man power, availabilities of components, the duration of the project, and the type of the building. These factors can be divided into sixty sub factors. The most influential factor affecting the site layout due to the number of sub factors is the design of the building. It affects four components, particularly the equipment. From this finding, it can be concluded that the experts can see a vague picture of CSLP for the equipment by getting only the design of the building. However, it is not the most critical factor among the number of affected components. Site constraints and the traffic on the site are the most powerful factors affecting CSLP from this aspect. They influence seven components. Another finding is the importance of the site plan. The site plan affects greatly on the human-related facilities, for example, site offices, stores, and toilets.

Finally, the guideline is developed from these factors affecting. The guideline replicates the work processes from the management of experts. It is divided into three phases. The first phase is the early stage which requires factors that can be obtained from the document directly, for example, the height of the building, the shape of the site plan, and specifications from the owner. The result of this phase is the overview of components on the construction site layout. The second phase is the middle stage. It can transform the overview of these components into primary site layout with the cooperation between the user and the guideline. The last phase is the checking stage. The primary site layout from the second phase can be checked by this stage to raise safety and productivity of the planning.

The system is developed by using the guideline as a core. The system is based on IF-THEN-ELSE with the ability to receive values of factors from the user and return the suggestion of after calculating these values. The system is programed on Ren'py with the simplified Python computer language. The system can facilitate the usage of the guideline and make the guideline easier to be implemented with the interactive behaviour.

The validation is conducted and separated into two parts. First the knowledge rule bases inside the knowledge base are compared with the real practice basis from another case study. It is revealed that the external validity is achieved due to the majority of rule bases that are similar in the principle treating the decision making when the same condition occurs. The second part is the validation of the system whether it can serve its main objective to assist low expertise engineers doing CSLP.

The results show that with the assistance of the system, the low expertise engineer can do CSLP also. The layouts of the low expertise engineers have some aspects which are similar to the layouts of the expert. This is evidence that the system can serve its objective assisting the low expertise engineers. Moreover, the high expertise engineers can also summarize their current knowledge and experience with the knowledge from the system to expand their abilities to plan for the construction site layout.

8.2 Applications and benefits of the system

This system can support the low expertise planners to be able to acquire the knowledge and work processes from the experts. They can also receive the reasons behind the decisions made by the experts when they manage CSLP. The experienced engineers are able to gain advantage from this system also. They can benchmark and gain more vision for their CSLP. Consequently, they can have more knowledge and be able to discover the possible improvement for their works.

8.3 Research outcomes

The outcomes of this study are (1) the showcase of factors affecting CSLP, (2) the guideline replicating the processes of the planning, and (3) the system assisting CSLP. Moreover, the methodology to gain the result of the study can be further utilized as an example of the qualitative research in construction engineering, and management studies.

8.4 Research contributions

(1) The factors affecting CSLP is revealed. Consequently, its knowledge becomes concrete and let the further research to be able to investigate deeper into these factors.

(2) The methodology of this research can be an approach for the study in qualitative environment, especially CSLP for construction projects. A knowledge-based supporting system can imitate the decision making of experts and provide the in-depth knowledge for the reason behind which is suitable with the construction aspect that requires high knowledge and experience..

(3) The output of this research is a system assisting CSLP. It can assist the low expertise engineers to be able to do the planning and receive the workable

construction site layout. Knowledge and experience are two major criteria which are important for the planning of construction site layout. Unfortunately, these attributes cannot be achieved by a short period of time. By implementing this study, it can raise the overall quality of CSLP and reduce losses and casualties from the construction environment.

8.5 Recommendations and limitations

(1) This system is developed to support CSLP in the first phase of the high-rise reinforced concrete building construction project. It does not support the planning in the dynamic environment.

(2) The system specifies only thirteen components which the expert panel agrees among themselves that they are crucial and has to be considered in the first phase of the construction project. Other components are not supported by this system. However, they can be investigated further with the same research methodology.

(3) Some decision makings still require the final judgement from the planner.

(4) The knowledge inside the system comes from the experience and knowledge of a group of experts, judging on five case studies. It does not mean that it is correct in every aspect. The user should consider with caution when the system has to be utilized with the project that is different from the case studies.

(5) The sixty factors are classified on thirteen categories. They might vary based on different project locations.

8.6 Further research

(1) The system can be further linked with numerous visualization techniques to facilitate convenience for users, for example, using CAD based graphic or virtual reality.

(2) The knowledge rule bases can be expanded to support other types of buildings such as steel structure.

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APPENDIX

Appendix A

Data from exploratory interview

Table A1 shows the calculation of the site office's size

	Calculate by multiply area per a person with the number of people who required to have seats in site office		Follow from TOR
	Newly build	Use container	
Site office's size	8	3	3

Table A2 shows the location of the site office

	In the front part of the site	Places where they don't interfere with other works and can stay for a long time	Engineers can come to check the work conveniently	Engineers can see all around	Move into the building when it is finished the first few floors
The location of the site office	7	3	2	2	2

Table A3 shows the principle of separating site office of each party

	Separate each sector clearly	
	Have Owner, Contractor, and Consultant stay together	Have Contractor, Subcontractor, and Consultant stay together
The principles for the designing for site offices of each sector	7	2

Table A4 shows the location of the guard box

	At the gates	Next to the places storing valuable things	At entrances of the building
The location of the guard box	11	4	2

Table A5 shows the principle of choosing the number of staff's toilet

	Consider from suitability	A room for men and a room for women
The principle of choosing the number of staff's toilet	6	2

Table A6 shows the location of the staff's toilet

	Inside the site office	Near/Next to site office
The location of the staff's toilet	6	2

Table A7 shows the principle of choosing the number of labour's toilet

	Follow the regulation	Ten people per room
The principle of choosing the number of labour's toilet	7	3

Table A8 shows the location of the labour's toilet

	Shirk / close to the wall	Location on the construction site		
		Near the building	Far away from building	Next to the staff's toilet
The location of labour's toilet	6	5	3	2

Table A9 shows the location of the labour camp

	Should not have in the construction site	Design to be a room for two people each
The location of the labour camp	8	3

Table A10 shows the opinion about having dining area on the construction site

	Should have in the construction site	Not necessary to have on the construction site
The opinion about having dining area on the construction site	8	3

Table A11 shows the principle to specify the area of the dining area

	Calculate by area per a person	Calculate by sum up the area
The principle to specify the area of the dining area	3	2

Table A12 shows the location of the dining area

	In the constructed building	Next to the labour camp	Parking building
The location of the dining area	3	2	2

Table A13 shows the location of the service workshop

	Next to the store	Not necessary to have service workshop on the construction site
The location of the service workshop	9	2

Table A14 shows the location of the store

	Next to the site office	Next to the constructed building	Next to the guard box
The location of the store	5	4	2

Table A15 shows the principle of using types of store

	Normal construction	Use container
The principle of using types of store	9	2

Table A16 shows store's accessibility

	Tower crane can reach	Trucks can reach
Store's accessibility	5	2

Table A17 shows the principle of choosing the cement store's size

	Consider from quantity of work from plan	Consider from the area that can use	Consider from trucks that come to deliver
The principle of choosing the cement store's size	7	2	2

Table A18 shows cement store's accessibility

	Tower crane can reach	Trucks can reach
Cement store's accessibility	6	3

Table A19 shows the location of the cement store

	Next to the store	Distribute to each floor	Next to the laydown area	At the front of the construction site
The location of cement store	6	2	2	2

Table A20 shows the principle of managing cement store

	Use panel to lift cement bags from the ground	Rain prevention		
		Use plastic sheet	Build roof and wall	Store inside the building
The principle of managing cement store	6	6	2	2

Table A21 shows the principle of choosing steel yard’s size

	Up to the quantity of the steel in each work plan	As much as possible
The principle of choosing steel yard’s size	9	2

Table A22 shows the location of the steel yard

	Next to the fabricate rebar yard	Next to the site road	Next to the construction area
The location of the steel yard	4	3	2

Table A23 shows steel yard’s accessibility

	Tower crane can reach	Trucks can reach
Steel yard’s accessibility	9	5

Table A24 shows the principle of managing steel yard

	Covered with plastic sheet	Covered with constructed roof
The principle of managing steel yard	8	2

Table A25 shows the location of the fabricated rebar yard

	Next to the steel yard	In front of the work place
The location of the fabricated rebar yard	8	2

Table A26 shows fabricated rebar yard’s accessibility

	Tower crane can reach
Fabricated rebar yard’s accessibility	6

Table A27 shows the location of the formwork storage yard

	Wherever on the site	Not necessary	Next to the store
The location of the formwork storage yard	5	3	2

Table A28 shows formwork storage yard's accessibility

	Tower crane can reach	Trucks can reach	No need for the labour to be accessed
Formwork storage yard's accessibility	6	2	3

Table A29 shows location of fabricated formwork yard

	In front of the work place	Next to the formwork storage yard
The location of the fabricated formwork yard	9	2

Table A30 shows the location of the fabricated pipe yard

	In front of the work place	Next to the systematic store	Next to the subcontractor office	Not necessary
The location of the fabricated pipe yard	4	3	2	3

Table A31 shows fabricated pipe yard's accessibility

	Trucks can reach
Fabricated pipe yard's accessibility	3

Table A32 shows the managing of welding shop

	Do it from outside	Have a proper room
The principle of managing Welding Shop	3	3

Table A33 shows the location of the welding shop

	In front of the work place	Free space somewhere on the construction site
The location of the welding shop	4	2

Table A34 shows the location of the concrete plant

	At the corner or close to the wall of the construction site	Far away from the construction area	Should not have on the construction site
The location of the concrete plant	3	2	2

Table A35 shows concrete plant's accessibility

	Trucks can reach
Concrete plant's accessibility	4

Table A36 shows the location of the water tank

	Locate at places which require water, for example, site office and toilet	For the structural work	
		Locate tank at the ground and pump the water up	Use the same tank as the building, pump the water up to the tank and use gravity to deliver
The location of the water tank	11	7	3

Table A37 shows the location of the laydown area

	At the front of the construction site	Next to the store	Free space anywhere on the construction site
The location of the laydown area	4	3	4

Table A38 shows laydown area accessibility

	Tower crane can reach	Trucks can reach
Laydown area's accessibility	7	5

Table A39 shows site gate's height

	Metres	
	5	6
Site gate's height	3	3

Table A40 shows site gate's width

	Metres						
	4	5	6	7	8	9	10
site gate's width	2	2	3	3	5	4	3

Table A41 shows the location of the truck's tires washing yard

	Next to the site gate	Next to the site gate but shirk from the entrance
The location of the truck's tires washing yard	6	4

Table A42 shows the principle of choosing truck's tires washing yard's type

	Dig a hole which a whole truck can go in	Use water jet to clean the tires
The principle of choosing truck's tires washing yard's type	7	2

Table A43 shows the location of the concrete pump

	For the stationary one			For the mobile one, park on the site road and pump up to the building
	Close to the building	Close to the lift core	Close to the site road	
The location of the concrete pump	7	2	2	11

Table A44 shows concrete pump's accessibility

	Cement trucks should be able to access and turn their back to the pump conveniently	Have free space where the trucks can park for waiting
Concrete pump's accessibility	11	4

Table A45 shows the location of the tower crane

	Exact place				Consider from the shape of the building	Set in the place which can remove easily
	Inside the building		Outside of the building			
	In the lift core	Block the floor	Not necessary to close to the building	Close to the building		
The location of the tower crane	5	1	4	2	3	2

Table A46 shows the principle of choosing tower crane's type and jib range

	Can support the transport works thoroughly	Carefully choose the jib type and range which do not reach out of the site	Put the first tower crane to be as big as possible and then, put small ones to cover all of the transport works. Beware of the height also
The principle of choosing tower crane's type and jib range	11	2	2

Table A47 shows the principle of choosing passenger lift

	Use a pair of passenger lifts	Compare the work space before choosing	Consider the shape of the building
The principle of choosing passenger lift	7	2	2

Table A48 shows the location of the passenger lift

	Set at the side where does not have to beautifully finish or can finish it later	Set at the side which can transport conveniently	Set at the side where does not interfere other works / is not in the position of other equipment pathway
The location of the passenger lift	7	3	2

Table A49 shows the principle of choosing parking lots' size

	Consider from the number of cars which have to come to park multiply by area per a car	Consider when there are some free space left
The principle of choosing parking lots' size	6	5

Table A50 shows the location of the parking lots

	Next to the site office
The location of the parking lot	5

Table A51 shows the principle of choosing site road's width

	Metres							
	3	4	5	6	7	8	9	10
The principle of choosing site road's width	3	4	5	11	6	5	3	2

Table A52 shows the facilities which should be paid attention in Thai construction site

	Temporary Transformer	Systematic Store	Waste Chimney
The facilities which should be paid attention on Thai construction site	5	2	2

Appendix B

The summed indices

Table B1 shows the summed indices of the tower cranes

Site	Type of the building	Duration	Expert	Amount and type of tower cranes	Design of the site		Site constraints	Position				Safety			
					Cover all the building	Cover between the building and the storage	Attach to	Lift Core/ Stairs core (Fireman)	Attach to the building	Inside the building but not in the Lift Core	Separate from the building	Swing path is in the site	Material traveling paths do not intercept with Office related components	Swing path is clear of obstructed surrounding	Prepare the roof for the pedestrian way near the construction site
Site A	Inter-national Office	30 months	Expert 1	1 fixed (Big)	/	/		/				/	/	/	
			Expert 2	2 fixed	/	/		/				/	/	/	
			Expert 3	1 fixed (Big)	/	/		/				/	/	/	
			Expert 4	2 fixed	/	/	Prefab x 2		/			/	/	/	
			Expert 5	2 fixed	/	/	Prefab	/	/			/	/	/	
Site B	Multi-purpose Building	32 Months	Expert 1	1 fixed		/	Lift core		/				/		/
			Expert 2	1 fixed		/		/					/		/
			Expert 3	1 Articulated		/				/		/	/	/	/
			Expert 4	1 fixed		/	Lift core		/				/		/
			Expert 5	1 fixed		/	Prefab		/				/		/
Site C	Office and Shop-ping Mall	30 Months	Expert 1	2 fixed	/	/	Normal floor	/		/			/	/	/
			Expert 2	2 fixed	/	/	Normal floor	/		/			/	/	/
			Expert 3	2 fixed	/	/	Masonry	/	/			/	/	/	/
			Expert 4	3 fixed	/	/	Masonry x 3		/				/	/	/
			Expert 5	3 fixed	/	/	Masonry	/	/	/			/	/	/
Site D	Dorm	32 Months	Expert 1	2 fixed	/	/		/					/	/	/
			Expert 2	2 fixed	/	/		/					/	/	/
			Expert 3	2 fixed	/	/		/					/	/	/
			Expert 4	2 fixed	/	/	Prefab x 2		/				/	/	/
			Expert 5	2 fixed	/	/	Masonry x 2		/				/	/	/
Site E	Shop-ping Mall	24 Months	Expert 1	2 fixed 2 Arti	/	/	Stairs	/				/	/	/	/
			Expert 2	1 fixed 3 Arti	/	/	Stairs	/				/	/	/	/
			Expert 3	1 fixed 2 Arti	/	/	Stairs	/				/	/	/	/
			Expert 4	1 fixed 3 Arti	/	/	Masonry/Floor		/	/		/	/	/	/
			Expert 5	4 fixed 1 Arti	/	/	Lift core/Stairs		/	/		/	/	/	/

Table B2 shows the summed indices of the laydown area

Site	Type of the building	Expert	Site constraints				
			Correlated to site space	Accessibility		Position (into, next to)	
			Can be placed at free spaces wherever in the site	Tower cranes can reach	Trucks can reach	The front of the site	Store
Site A	International Office	Expert 1	/	/	/	/	
		Expert 2		/	/		
		Expert 3		/	/	/	
		Expert 4		/	/		
		Expert 5	/	/	/	/	
Site B	Multipurpose Building	Expert 1		/	/		
		Expert 2		/	/	/	
		Expert 3		/	/		
		Expert 4		/	/	/	/
		Expert 5		/	/	/	
Site C	Office and Shopping Mall	Expert 1	/	/	/		
		Expert 2	/	/	/		
		Expert 3		/	/	/	
		Expert 4		/	/	/	/
		Expert 5		/	/	/	
Site D	Dorm	Expert 1	/	/	/	/	
		Expert 2		/	/	/	
		Expert 3		/	/	/	/
		Expert 4		/	/	/	/
		Expert 5		/	/	/	
Site E	Shopping Mall	Expert 1	/	/	/	/	/
		Expert 2	/	/	/	/	
		Expert 3	/	/	/	/	
		Expert 4		/	/	/	
		Expert 5		/	/	/	

Table B3 shows the summed indices of the concrete pump

Site	Type of the building	Number of floors	Location of the site	Expert	Method of work		Design of the site	Site Constraint									
								Correlated to site space		Accessibility		Position (Pipe)			Position (Pump)		
			The site has traffic jam		Static pump usage	Mobile pump usage	Cover all the building	Free space for trucks to wait	Trucks wait outside of the site	Trucks can reach	Trucks can make U-turn	Lift Core	Systematical Shaft	Attach to the side of the building	Close to the building at the center of a side	Close to the building but not in the center	Close to the area which pipe has to go through
Site A	International Office	21		Expert 1	/		/	/		/			/			/	/
				Expert 2	/		/	/		/				/		/	/
				Expert 3		/	/	/									
				Expert 4	/		/	/		/				/		/	/
				Expert 5	/		/	/		/				/	/		/
Site B	Multi-purpose Building	11		Expert 1	/		/	/		/			/		/		/
				Expert 2	/		/	/		/			/			/	/
				Expert 3	/		/	/		/		/ (Outside)			/		/
				Expert 4	/		/	/		/				/	/		/
				Expert 5	/		/	/		/		/ (Outside)			/		/
Site C	Office and Shopping Mall	44	/	Expert 1	/		/	/		/	/	/				/	/
				Expert 2	/		/	/		/	/	/			/		
				Expert 3	/		/	/		/	/	/				/	
				Expert 4	/		/	/		/	/			/	/		/
				Expert 5	/		/	/		/	/	/				/	
Site D	Dorm	17	/ (with some parking area)	Expert 1		/	/		/								
				Expert 2		/	/		/								
				Expert 3		/	/		/								
				Expert 4		/	/		/								
				Expert 5	/		/		/	/				/	/		
Site E	Shopping Mall	7	/	Expert 1		/	/		/ (Night)								
				Expert 2		/	/		/ (Night)								
				Expert 3		/	/		/ (Night)								
				Expert 4		/	/		/ (Night)								
				Expert 5		/	/		/ (Night)								

Table B4 shows the summed indices of the mobile cement plant

Site	Type of the building	Site Constraints	Design	Location of the site		Expert	Site constraints					
							Correlated to site space		Accessibility		Position next to	
		Free space (sq.m.)	Bill of quantity	Has surrounding neighborhood	Has traffic jam		Far away from site office	Position near the entrance gate	Trucks can reach	Trucks can make U-turn	Corner	Wall
Site A	International Office	6,876	>20,000 cu.m		/	Expert 1	/	/	/	/	/	
						Expert 2	/		/	/	/	
						Expert 3		/	/	/	/	
						Expert 4	/	/	/	/	/	
						Expert 5			/	/	/	
Site B	Multi-purpose Building	1,745		/		Expert 1						
						Expert 2						
						Expert 3						
						Expert 4						
						Expert 5						
Site C	Office and Shopping Mall	2,206/		/	/	Expert 1						
						Expert 2						
						Expert 3						
						Expert 4						
						Expert 5						
Site D	Dorm	2,367/		/	/	Expert 1						
						Expert 2						
						Expert 3						
						Expert 4						
						Expert 5						
Site E	Shopping Mall	2,063		/	/	Expert 1						
						Expert 2						
						Expert 3						
						Expert 4						
						Expert 5						

Table B5 shows the summed indices of the passenger lift

Site	Type of the building	Duration	Area per a floor (estimated)	Number of stories	Expert	Amount of Passenger lifts	Design	Site Constraint				Safety	
								Correlated to site space	Position				
							Finishing of the wall which lift's rail attached	Hidden from visitor's view	In front of the site	At the back of the side	At the side of the site	Located outside of tower cranes' swings	No one pass around the passenger lift
Site A	International Office	30 months	3,234 sq.m	22	Expert 1	2	Prefab	/		/			/
					Expert 2	2	Prefab	/		/			/
					Expert 3	2	Prefab	/		/			/
					Expert 4	2	Prefab	/		/			/
					Expert 5	2	Prefab	/		/			/
Site B	Multi-purpose Building	32 Months	1,583 sq.m.	11	Expert 1	1	Prefab	/			/		/
					Expert 2	1	Prefab		/				/
					Expert 3	2	Prefab	/			/		/
					Expert 4	2	Prefab		/				/
					Expert 5	2	Prefab		/				/
Site C	Office and Shopping Mall	30 Months	6,240 sq.m.	44	Expert 1	2	Prefab	/			/		/
					Expert 2	4	Prefab(2), Masonry Wall(2)	/		/			/
					Expert 3	2	Prefab	/			/		/
					Expert 4	4	Prefab				/		/
					Expert 5	2	Masonry Wall				/		/
Site D	Dorm	32 Months	1,620 sq.m.	17	Expert 1	1	Masonry Wall		/ (Center)				/
					Expert 2	2	Prefab		/				/
					Expert 3	2	Prefab		/				/
					Expert 4	2	Prefab		/				/
					Expert 5	2	Prefab		/ (Separate)				/
Site E	Shopping Mall	24 Months	10,639 sq.m.	7	Expert 1	4	Prefab		/		/		/
					Expert 2	4	Prefab				/		/
					Expert 3	4	Prefab		.		/		/
					Expert 4	4	Prefab				/		/
					Expert 5	4	Prefab				/		/

Table B6 shows the summed indices of the site office

Site	Type of the building	TOR/Spe-cification about site office	Expert	TOR/Specification		Site Constraint					Safety	
						Correlated to site space	Position					
				Build a new site office	Use a container	Have clear view of the site	In front of the site	Move into the building	Use other building	Others	Safe from tower cranes and passenger lifts	Safe from material path
Site A	Inter-national Office		Expert 1	/		/				/ (Back)	/	/
			Expert 2		/	/	/				/	/
			Expert 3	/		/				/ (Back)	/	/
			Expert 4	/		/				/ (Back)	/	/
			Expert 5	/		/	/				/	/
Site B	Multi-purpose Build-ing		Expert 1	/			/				/	/
			Expert 2		/		/				/	/
			Expert 3	/		/	/				/	/
			Expert 4	/			/				/	/
			Expert 5	/			/				/	/
Site C	Office and Shop-ping Mall	Can use nearby building as a site office	Expert 1		/				/		/	/
			Expert 2		/		/					/
			Expert 3		/					/ (Side)	/	/
			Expert 4		/		/	/				/
			Expert 5	/			/				/	/
Site D	Dorm	Each engineer must have at least 9 sq.m. work space	Expert 1	/		/	/					/
			Expert 2	/		/	/					/
			Expert 3	/		/	/					/
			Expert 4	/		/	/					/
			Expert 5	/		/	/					/
Site E	Shop-ping Mall		Expert 1	/			/					/
			Expert 2		/					/ (Back)		/
			Expert 3		/		/	/				/
			Expert 4	/			/					/
			Expert 5		/		/	/				/

Table B7 shows the summed indices of the steel yard

Site	Type of the building	Expert	Area of the storage	Method of works		Site Constraint					
						Accessibility		Position			
				Judge from the quantity of the work	As many as possible	Tower cranes can reach	Trucks can reach	Close to walls	Close to construction area	Close to fabricated rebar yard	Close to site road
Site A	International Office	Expert 1	266		/	/	/	/	/	/	/
		Expert 2	417		/	/	/			/	/
		Expert 3	431		/	/	/	/		/	/
		Expert 4	431		/	/	/	/		/	/
		Expert 5	220		/	/	/			/	/
Site B	Multi-purpose Building	Expert 1	126	/		/	/	/		/	/
		Expert 2	109	/		/	/	/		/	/
		Expert 3	114	/		/	/	/	/	/	/
		Expert 4	122	/		/	/	/		/	/
		Expert 5	104	/		/	/	/		/	/
Site C	Office and Shopping Mall	Expert 1	341	/		/	/	/	/	/	/
		Expert 2	158	/		/		/	/	/	
		Expert 3*	859		/	/			/	/	
		Expert 4*	100	/		/		/	/	/	
		Expert 5	224	/		/		/	/	/	
Site D	Dorm	Expert 1	269		/	/	/	/		/	/
		Expert 2	243		/	/	/	/		/	/
		Expert 3	113	/		/	/		/	/	/
		Expert 4	187	/		/		/		/	
		Expert 5	160	/		/		/		/	
Site E	Shopping Mall	Expert 1	233	/		/		/	/	/	
		Expert 2	157	/		/		/	/	/	
		Expert 3	166	/		/		/	/	/	
		Expert 4	176	/		/		/	/	/	
		Expert 5	318	/		/		/	/	/	

*Expert 3 and 4 at Site C plans the work into 2 phases by placing the steel yard on the podium part and finish the tower part first

Table B8 shows the summed indices of the store

Site	Type of the building	Expert	Designer's decision		Site constraints				
					Accessibility		Position next to		Has to be moved to other location such as, inside the building
			Newly build	Use a container	Tower cranes can reach	Trucks can reach	Site office	Guard box	
Site A	International Office	Expert 1	/			/	/		
		Expert 2	/			/			
		Expert 3	/			/	/		
		Expert 4	/			/	/		
		Expert 5	/		/	/	/		
Site B	Multipurpose Building	Expert 1	/		/	/			
		Expert 2		/	/	/	/	/	
		Expert 3	/			/	/	/	
		Expert 4	/		/	/	/	/	
		Expert 5	/			/			
Site C	Office and Shopping Mall	Expert 1	/		/	/		/	
		Expert 2		/	/		/		
		Expert 3	/				/	/	
		Expert 4		/	/	/	/	/	/
		Expert 5	/			/	/		
Site D	Dorm	Expert 1	/		/		/		
		Expert 2		/	/				
		Expert 3		/	/		/		
		Expert 4	/		/			/	
		Expert 5		/	/		/		
Site E	Shopping Mall	Expert 1	/		/				
		Expert 2		/	/	/		/	/
		Expert 3		/	/	/	/		/
		Expert 4	/		/		/		
		Expert 5	/		/				

Table B9 shows the summed indices of the toilet

Site	Type of the building	Expert	Regulation	Designer's decision		Site constraints				Safety		
						Correlated to site space	Position next to			Located out of		
			Follow the regulation	Separate between labour's toilet and engineer's toilet	Staff's toilet is located in the site office	Hidden from visitor's view	Wall near Man hole	Construction area	Site office	Tower cranes' swing	Material traveling path	Passenger lift area
Site A	International Office	Expert 1	/	/	/					/	/	/
		Expert 2	/	/		/	/	/		/	/	/
		Expert 3	/	/	/		/			/	/	/
		Expert 4	/	/	/	/	/	/	/		/	/
		Expert 5	/	/	/	/	/	/			/	/
Site B	Multipurpose Building	Expert 1	/	/	/		/		/		/	/
		Expert 2	/	/			/		/	/	/	/
		Expert 3	/	/	/		/		/	/	/	/
		Expert 4	/	/	/		/		/		/	/
		Expert 5	/	/	/			/			/	/
Site C	Office and Shopping Mall	Expert 1	/	/	/	/		/		/	/	/
		Expert 2	/	/			/	/	/		/	/
		Expert 3	/	/	/	/	/	/		/	/	/
		Expert 4	/	/		/	/	/			/	/
		Expert 5	/	/	/		/	/	/	/	/	/
Site D	Dorm	Expert 1	/	/	/	/		/			/	/
		Expert 2	/	/	/	/	/			/	/	/
		Expert 3	/	/	/	/	/			/	/	/
		Expert 4	/	/	/	/		/			/	/
		Expert 5	/	/	/	/		/			/	/
Site E	Shopping Mall	Expert 1	/	/	/	/	/	/			/	/
		Expert 2	/	/		/	/	/			/	/
		Expert 3	/	/			/	/			/	/
		Expert 4	/	/	/	/	/	/			/	/
		Expert 5	/	/			/	/			/	/

Table B10 shows the summed indices of the general information about the site office and the toilet

Site	Expert	Site Office			WC (number of rooms or just follow the law)						
		Size (sq.m.)	Type		Staff			Labour			
			Build a new one	Use prefabricated material	Area	Rooms	Average	Area	Rooms	Average	Average per site
	1	348.16	/		34.82	2	17.41	103.22	9	11.47	
	2	122.88		/	45.2	3	15.07	30.72	5	6.14	
A	3	81.92	/		9.83	2	4.92	81.92	6	13.65	10.99
	4	387.07	/		68.81	4	17.20	90.11	7	12.87	
	5	81.92	/		16.38	2	8.19	108.13	10	10.81	
	1	199.8	/		16.2	4	4.05	56.7	7	8.10	
	2	39.6		/	12	3	4.00	15	5	3.00	
B	3	41.76	/		7.2	2	3.60	30.6	6	5.10	4.75
	4	132.84	/		8.82	2	4.41	25.2	5	5.04	
	5	30.24	/		6.3	2	3.15	17.64	7	2.52	
	1	100	Uses other building		30	4	7.50	104.22	10	10.42	
	2	104.22		/	104.22*	12	12.00	104.22*	12	8.69	
C	3	97.272		/	56.28*	15	15.00	56.28*	15	3.75	7.46
	4	208.44		/ (Move into the building later)	31.27	7	4.47	99	11	9.00	
	5	76.43	/		10.42	2	5.21	54.19	10	5.42	
	1	304	/		21.28	2	10.64	46.17	6	7.70	
	2	242.44	/		27.36	2	13.68	82.08	10	8.21	
D	3	118.75	/		9.5	2	4.75	96.9	8	12.11	7.39
	4	155.99	/		9.5	2	4.75	31.92	14	2.28	
	5	96.14	/		10.45	2	5.23	53.2	8	6.65	

Table B10 (Continued) shows the summed indices of the general information about the site office and the toilet

Site	Expert	Site Office			WC (number of rooms or just follow the law)						
		Size (sq.m.)	Type		Staff			Labour			
			Build a new one	Use prefabricated material	Area	Rooms	Average	Area	Rooms	Average	Average per site
E	1	94.64	/		26.46	3	8.82	49.68	10	4.97	7.28
	2	75.6		/	7.28	2	3.64	71.28	7	10.18	
	3	83.7		/ (Move into the building later)	10.84	2	5.42	64.8	8	8.10	
	4	189	/		22.68	2	11.34	140.4	15	9.36	
	5	54		/ (Move into the building later)	16.2	3	5.40	22.68	6	3.78	
		Average	157.71	98.35	* = Staff use with labours						
					19.95	2.65		64.16	8.26		
				SD	14.60	1.17		33.90	2.64		
			Average area per room		7.52 sq.m.			7.77 sq.m.			

Table B11 shows the summed indices of the steel yard's size and policy

Site	Expert	Area of the storage	Method of works		% Steel yard's area and Site area	Ave-rage	SD	% of ave-rage area vs area of the site	% of ave-rage area vs area per floor	% of ave-rage area vs free space
			Judge from the quan-tity of the work	As many as possible						
A	1	266		/	3.87	353.00	91.13	3.49	10.92	5.13
	2	417		/	6.06					
	3	431		/	6.27					
	4	431		/	6.27					
	5	220		/	3.20					
B	1	126	/		7.22	115.00	8.10	3.46	7.26	6.59
	2	109	/		6.25					
	3	114	/		6.53					
	4	122	/		6.99					
	5	104	/		5.96					
C	1	341	/		15.46	859.00				
	2	158	/		7.16	532.38				
	3	859		/	38.94	205.75	89.57	2.44	3.30	9.33
	4	100	/		4.53					
	5	224	/		10.15					
D	1	269		/	11.36	256.00	13.00	6.42	15.80	10.82
	2	243		/	10.27	204.67		5.13	12.63	8.65
	3	113	/		4.77	153.33	30.58	3.85	9.47	6.48
	4	187	/		7.90					
	5	160	/		6.76					
E	1	233	/		11.29	210.00	60.16	1.60	1.89	10.18
	2	157	/		7.61					
	3	166	/		8.05					
	4	176	/		8.53					
	5	318	/		15.41					

	= as many as possible
	= quantity of work

Table B12 shows the relationship between %free space vs (% of average steel yard area vs site's area) for sustaining the work cycle

%free space vs (% of average steel yard area vs site's area) for sustaining the work cycle	
% Free space	% Steel vs Free
59.37	3.85
52.43	3.46
26.12	2.44
15.67	1.60

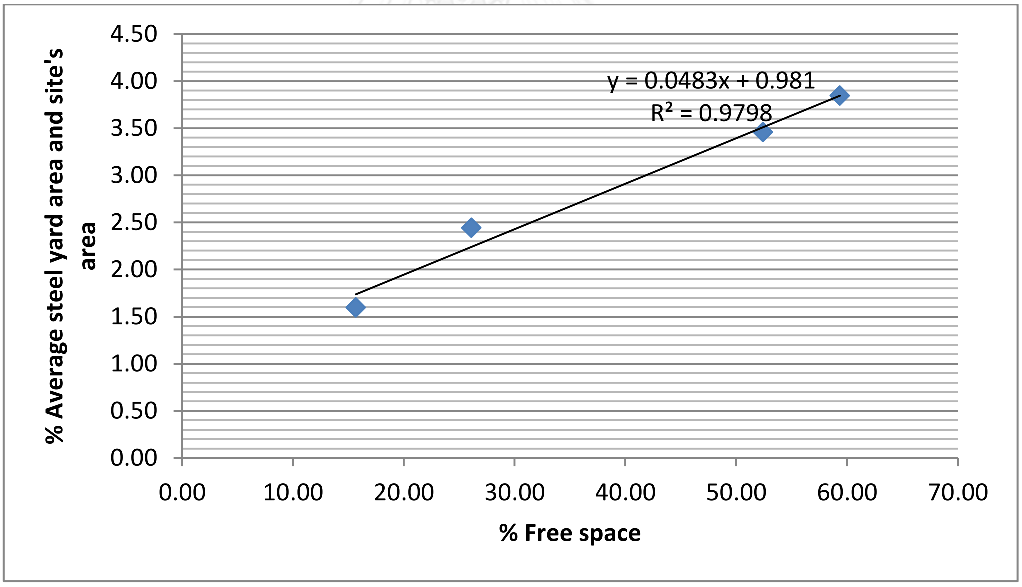

Figure B1 shows the graph of %free space vs (% of average steel yard area vs site's area) for sustaining the work cycle

Table B13 shows the extended summed indices of the laydown area

Site	Type of the building	The entrance of the site	Expert	The entranced used	Trucks can access into the site	Traffic direction	Position of the Laydown area	Size (sq.m.)	Average (sq.m.)	S.D. (sq.m.)
Site A	International Office	1	Expert 1	2 (1 Staff Door)	Yes	Cycle	In front of the site	172.03	247.56	199.41
			Expert 2	2 (1 Staff Door)	Yes	Cycle	Inside of the site	144.18		
			Expert 3	2 (1 Staff Door)	Yes	Cycle	In front of the site	122.88		
			Expert 4	2 (1 Staff Door)	Yes	Cycle	Inside of the site	645.12		
			Expert 5	1	Yes	Cycle	In front of the site	153.60		
Site B	Multipurpose Building	2	Expert 1	2	Yes	1 way in 1 way out	Inside of the site	121.50	120.71	37.15
			Expert 2	2	Yes	1 way in 1 way out	In front of the site	52.65		
			Expert 3	2	Yes	1 way in 1 way out	Inside of the site	159.39		
			Expert 4	2	Yes	1 way in 1 way out	In front of the site	121.50		
			Expert 5	2	Yes	1 way in 1 way out	In front of the site	148.50		
Site C	Office and Shopping Mall	2	Expert 1	1	Yes	Cycle	Inside of the site	145.39	233.35	88.68
			Expert 2	1	Yes	Cycle	Inside of the site	194.54		
			Expert 3	1	Yes	Cycle	In front of the site	225.81		
			Expert 4	1	Yes	Cycle	In front of the site	402.98		
			Expert 5	1	Yes	Cycle	In front of the site	198.02		

Table B13 (Continued) shows the extended summed indices of the laydown area

Site	Type of the building	The entrance of the site	Expert	The entranced used	Trucks can access into the site	Traffic direction	Position of the Laydown area	Size (sq.m.)	Average (sq.m.)	S.D. (sq.m.)
Site D	Dorm	1	Expert 1	1	No	Park and reverse	In front of the site	266.42	207.81	59.04
			Expert 2	1	No	Park and reverse	In front of the site	190.30		
			Expert 3	1	No	Park and reverse	In front of the site	209.33		
			Expert 4	1	No	Park and reverse	In front of the site	106.57		
			Expert 5	1	No	Park and reverse	In front of the site	266.42		
Site E	Shopping Mall	1	Expert 1	1	No	Park and reverse	In front of the site	553.50	284.09	139.89
			Expert 2	2 (1 Staff Door)	No	Park and reverse	In front of the site	241.92		
			Expert 3	1	No	Park and reverse	In front of the site	194.40		
			Expert 4	1	No	Park and reverse	In front of the site	270.00		
			Expert 5	1	No	Park and reverse	In front of the site	160.65		

Table B14 shows the relationship between area of the site and the laydown area's size

Graph shows the relationship between area of the site and Laydown Area's size		
Site	Area of the site	Laydown Area
B	3,328	120.71
D	3,987	207.81
C	8,446	233.35
A	10,110	247.56
E	13,165	284.09

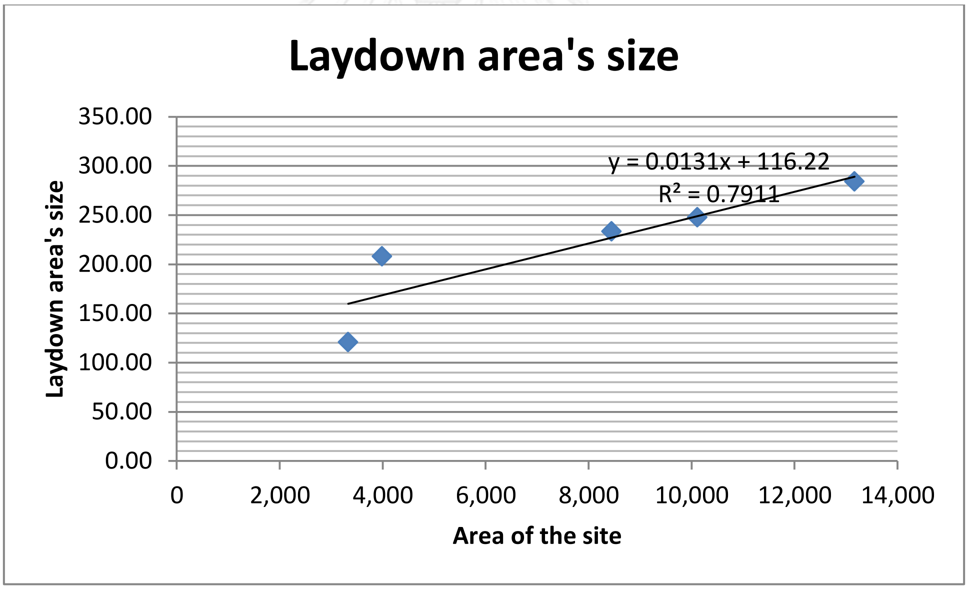

Figure B2 shows the graph of the relationship between area of the site and the laydown area's size

Table B15 shows the summed indices of the sites' properties

Site	Type of the building	Height	The entrance of the site	Expert	The entranced used	Trucks can access into the site	Traffic direction	Delivering	Barrier preventing falling objects for the outsiders or staff
Site A	International Office	21 Floors around 70 metres	1	Expert 1	2 (1 Staff's Door)	Yes	Cycle	Parking inside the site	At the small road side
				Expert 2	1	Yes	Cycle	Parking inside the site	At the small road side
				Expert 3	2 (1 Staff's Door)	Yes	Cycle	Parking inside the site	At the small road side
				Expert 4	2 (1 Staff's Door)	Yes	Cycle	Parking inside the site	At the small road side
				Expert 5	1	Yes	Cycle	Parking inside the site	At the small road side
Site B	Multipurpose Building	11 Floors 58.4 metres	2	Expert 1	2	Yes	1 way in 1 way out	Parking inside the site and in front of the site	At the small road side
				Expert 2	2	Yes	1 way in 1 way out	Parking inside the site and in front of the site	-
				Expert 3	2	Yes	1 way in 1 way out	Parking inside the site	-
				Expert 4	2	Yes	1 way in 1 way out	Parking inside the site and in front of the site	-
				Expert 5	2	Yes	1 way in 1 way out	Parking inside the site and in front of the site	At the small road side

Table B15 (Continued) shows the summed indices of the sites' properties

Site	Type of the building	Height	The entrance of the site	Expert	The entranced used	Trucks can access into the site	Traffic direction	Delivering	Barrier preventing falling objects for the outsiders or staff
Site C	Office and Shopping Mall	44 Floors around 150 metres	2	Expert 1	1	Yes	Cycle	Parking inside the site	Around the building
				Expert 2	1	Yes	Cycle	Parking inside the site	Around the building
				Expert 3	2 (1 Staff's Door)	Yes	Cycle	Parking inside the site	Around the building
				Expert 4	1	Yes	Cycle	Parking inside the site	Around the building
				Expert 5	2	Yes	1 way in 1 way out	Parking inside the site	Around the building
Site D	Dorm	17 Floors around 50 metres	1	Expert 1	1	No	Park and reverse	Parking in front of the site	Cover the walk path
				Expert 2	1	No	Park and reverse	Parking in front of the site	Cover the walk path
				Expert 3	1	No	Park and reverse	Parking in front of the site	Cover entire walk paths and the site
				Expert 4	1	No	Park and reverse	Parking in front of the site	Cover the walk path
				Expert 5	1	No	Park and reverse	Parking in front of the site	Cover entire walk paths and the site
Site E	Shopping Mall	7 Floors around 30 metres	1	Expert 1	1	No	Park and reverse	Parking inside the site and in front of the site (in the night)	At the small road side and the site office side
				Expert 2	2 (Staff's Door)	No	Park and reverse	Parking inside the site and in front of the site (in the night)	At the small road side and the site office side
				Expert 3	1	No	Park and reverse	Parking inside the site and in front of the site (in the night)	At the small road side and the site office side
				Expert 4	1	No	Park and reverse	Parking inside the site and in front of the site (in the night)	At the small road side and the site office side
				Expert 5	1	No	Park and reverse	Parking inside the site and in front of the site (in the night)	At the small road side and the site office side

Table B16 shows the extended summed indices of the site office

Site	Expert	Site Office			Area of the site office vs Area of the site	Area of the site office vs Area per floor	Area of the site office vs Area of free space	Build a new one	Use prefa-bricated material	Average from building a new one	Average from using prefabricated material
		Size (sq.m.)	Type: Build a new one	Type: Use prefabricated material							
A	1	348.16	/		0.03	0.11	0.03	348.16		224.77	122.88
	2	122.88		/	0.01	0.04	0.01		122.88		
	3	81.92	/		0.01	0.03	0.01	81.92			
	4	387.07	/		0.04	0.12	0.04	387.07			
	5	81.92	/		0.01	0.03	0.01	81.92			
B	1	199.8	/		0.06	0.13	0.11	199.8		101.16	39.6
	2	39.6		/	0.01	0.03	0.02		39.6		
	3	41.76	/		0.01	0.03	0.02	41.76			
	4	132.84	/		0.04	0.08	0.08	132.84			
	5	30.24	/		0.01	0.02	0.02	30.24			
C	1	Uses other building								76.43	156.33
	2	104.22		/	0.01	0.02	0.05		104.22		
	3	97.272		/							
	4	208.44		/ (Move into the building later)	0.02	0.03	0.09		208.44		
	5	76.43	/		0.01	0.01	0.03	76.43			

Table B16 (Continued) shows the extended summed indices of the site office

Site	Expert	Site Office			Area of the site of-fice vs Area of the site	Area of the site office vs Area per floor	Area of the site office vs Area of free space	Build a new one	Use prefabricated material	Average from building a new one	Average from using prefabricated material
		Size (sq.m.)	Type								
			Build a new one	Use prefa-brica-ted material							
D	1	304	/		0.08	0.19	0.13	304		183.46	
	2	242.44	/		0.06	0.15	0.10	242.44			
	3	118.75	/		0.03	0.07	0.05	118.75			
	4	155.99	/		0.04	0.10	0.07	155.99			
	5	96.14	/		0.02	0.06	0.04	96.14			
E	1	94.64	/		0.01	0.01	0.05	94.64		141.82	71.1
	2	75.6		/	0.01	0.01	0.04		75.6		
	3	83.7		/ (Move into the building later)	0.01	0.01	0.04		83.7		
	4	189	/		0.01	0.02	0.09	189			
	5	54		/ (Move into the building later)	0.00	0.00	0.03		54		

Table B17 shows the relationship between area of the site and % of site office and area of the site

Graph shows the relationship between area of the site and % of site office vs area of the site		
Site	Area of the site	%
E	13,165	0.75
A	10,110	2.02
C	8,446	1.54
D	3,987	4.60
B	3,328	2.67

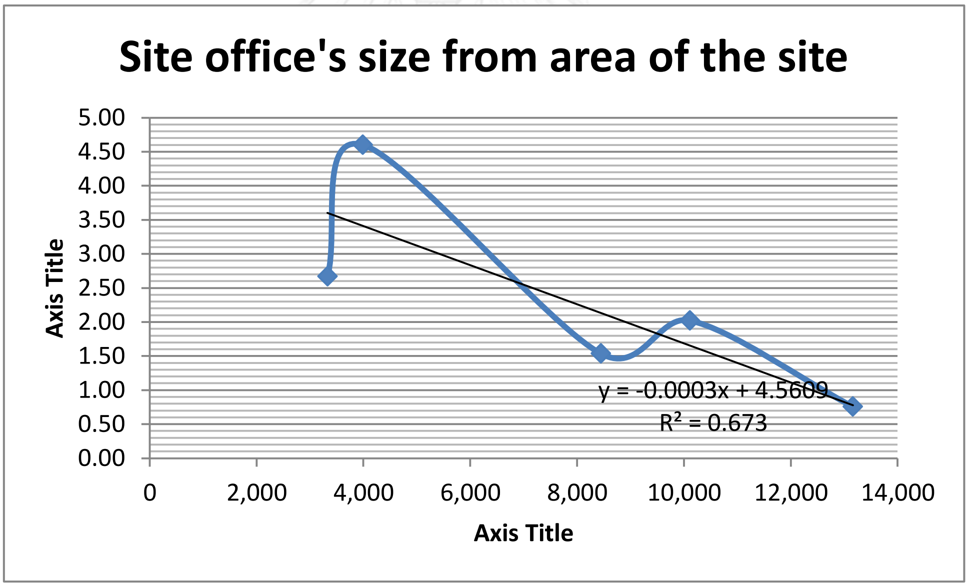

Figure B3 shows the graph of the relationship between area of the site and % of site office and area of the site

Table B18 shows the extended summed indices of passenger lifts

Site	Type of the building	Duration	Area per a floor (estimated) (sq.m.)	Number of stories	Expert	Amount of Passenger lifts	Design: Finishing of the wall which lift's rail attached	Design: The lift's rail can go through from the ground floor to the top floors	Area per floors per lifts (sq.m.)	Area covered for the entire building per lifts (sq.m.)	Longest distance from the passenger lifts which the labours have to walk to (m.)
Site A	International Office	30 months	3,234	22	1	2	Prefab	/	1617	35574	83.2
					2	2	Prefab	/	1617	35574	70.4
					3	2	Prefab	/	1617	35574	76.8
					4	2	Prefab	/	1617	35574	67.2
					5	2	Prefab	/	1617	35574	76.8
Site B	Multi-purpose Building	32 months	1,583	11	1	1	Prefab	/	1583	17413	57
					2	1	Prefab	/	1583	17413	60
					3	2	Prefab	/	791.5	8706.5	57
					4	2	Prefab	/	791.5	8706.5	57
					5	2	Prefab	/	791.5	8706.5	57
Site C	Office and Shop-ping Mall	30 months	6,240	44	1	2	Prefab	/	3120	67570	83.40
					2	4	Prefab (2), Masonry Wall (2)		1560	33785	58.38
					3	2	Prefab	/	3120	67570	87.57
					4	4	Prefab	/	1560	33785	75.06
					5	2	Masonry Wall	/	3120	67570	75.06

Table B18(Continued) shows the extended summed indices of passenger lifts

Site	Type of the building	Duration	Area per a floor (estimated) (sq.m.)	Number of stories	Expert	Amount of Passenger lifts	Design		Area per floors per lifts (sq.m.)	Area covered for the entire building per lifts (sq.m.)	Longest distance from the passenger lifts which the labours have to walk to (m.)
							Finishing of the wall which lift's rail attached	The lift's rail can go through from the ground floor to the top floors			
Site D	Dorm	32 months	1,620	17	1	1	Masonry Wall	/	1620	27540	60.9
					2	2	Prefab	/	810	13770	80.48
					3	2	Prefab	/	810	13770	58.73
					4	2	Prefab	/	810	13770	84.83
					5	2	Prefab	/	810	13770	36.98
Site E	Shopping Mall	24 months	10,639	7	1	4	Prefab	/	2659.75	18618.25	80.6
					2	4	Prefab	/	2659.75	18618.25	88.4
					3	4	Prefab	/	2659.75	18618.25	93.6
					4	4	Prefab	/	2659.75	18618.25	83.2
					5	4	Prefab	/	2659.75	18618.25	91
							Average (for the sustainability condition, counted as necessary number only)		1962.75	30089.45	72.02

Table B19 shows the extended summed indices of the store

Site	Type of the building	Expert	Designer's decision		Size (sq.m.)	Average (sq.m.)	S.D. (sq.m.)
			Newly build	Use a container			
Site A	International Office	Expert 1	/		69.27	54.46	21.61
		Expert 2	/		59.94		
		Expert 3	/		28.93		
		Expert 4	/		83.73		
		Expert 5	/		30.45		
Site B	Multipurpose Building	Expert 1	/		72.00	41.66	20.05
		Expert 2		/	14.82		
		Expert 3	/		40.50		
		Expert 4	/		27.00		
		Expert 5	/		54.00		
Site C	Office and Shopping Mall	Expert 1	/		103.18	76.39	21.82
		Expert 2		/	93.80		
		Expert 3	/		49.68		
		Expert 4		/	83.38		
		Expert 5	/		51.94		

Site	Area of site	Area per floor	Free Space
A	10,110	3,234	6,876
B	3,328	1,583	1,745
C	8,446	6,240	2,206
D	3,987	1,620	2,367
E	13,165	11,102	2,063

Ratio of Laydown area

Site	Area vs Area of site	Area vs Area per floor	Area vs Free Space
A	0.0054	0.0168	0.0079
B	0.0125	0.0263	0.0239
C	0.0090	0.0122	0.0346
D	0.0114	0.0282	0.0193
E	0.0036	0.0043	0.0230

%

Table B19(Continued) shows the extended summed indices of the store

Site	Type of the building	Expert	Designer's decision		Size (sq.m.)	Average (sq.m.)	S.D. (sq.m.)
			Newly build	Use a container			
Site D	Dorm	Expert 1	/		30.45	45.63	21.32
		Expert 2		/	76.12		
		Expert 3		/	27.40		
		Expert 4	/		27.40		
		Expert 5		/	66.80		
Site E	Shopping Mall	Expert 1	/		63.18	47.47	17.39
		Expert 2		/	54.00		
		Expert 3		/	54.00		
		Expert 4	/		52.65		
		Expert 5	/		13.50		

Site	Area vs Area of site	Area vs Area per floor	Area vs Free Space
A	0.54	1.68	0.79
B	1.25	2.63	2.39
C	0.90	1.22	3.46
D	1.14	2.82	1.93
E	0.36	0.43	2.30

Table B20 shows the relationship between area of the site and % of store and area of the site

Graph shows the relationship between area of the site and % of store vs area of the site		
Site	Area of the site	%
B	3328	1.25
D	3987	1.14
C	8446	0.90
A	10110	0.54
E	13165	0.36

Figure B4 shows the graph of the relationship between area of the site and % of store and area of the site

Table B21 shows the summed indices of the efficiency of tower cranes' coverage over the building and components

Site	Expert	Number of Tower cranes	Type	Efficiency												Site office coverage	Material path passes site office	Toilets coverage	Material path passes toilets
				Building coverage	%	Avg.	Laydown area coverage	%	Avg.	Steel yard coverage	%	Avg.	Store coverage	%	Avg.				
A	1	1	60x1	3,234	100		172.03	100		266	100		0.00	0		/		/	
	2	2	50x2	3,232	99.9		144.18	100		284.90	68.3		0.00	0					
	3	1	60x1	3,234	100	99.4	122.88	100	93.2	431	100	93.7	28.9	100	60				
	4	2	50x2	3,234	100		632.83	98.1		431	100		83.7	100		/		/	
	5	2	50x2	3,193	98.7		104.45	68		219.93	100		30.5	100		/		/	
B	1	1	50x1	1,270	80.2		121.50	100		126	100		0.00	0				/	
	2	1	40x1	1,324	83.7		52.65	100		109	100		14.8	100					
	3	1	40x1 (Luff)	1,583	100	88.5	159.39	100	97.2	114	100	94.4	0.00	0	39.4				
	4	1	50x1	1,264	79.9		121.50	100		87.58	71.8		26.2	97				/	
	5	1	50x1 (Luff)	1562.4	98.7		127.845	86.1		104	100		0.00	0				/	
C	1	2	40x2	6,206	99.5		145.39	100		341	100		103.2	100					
	2	2	40x2	6,240	100		194.54	100		158	100		93.8	100		/		/	
	3	2	35x1, 50x1	6,032	96.7	97.9	200.28	88.7	97.7	849.62	98.9	99.8	0.0	0	40.8				
	4	3	40x2 (Luff), 50x1	5,975	95.8		402.98	100		100	100		3.1	3.8		/		/	
	5	3	40x2 (Luff), 40x1	6,100	97.8		198.02	100		224	100		0.00	0					
D	1	2	50x2	1,620	100		266.42	100		269	100		30.5	100		/		/	
	2	2	50x2	1,620	100		190.30	100		243	100		76.1	100		/		/	
	3	2	50x2	1,620	100	100	209.33	100	100	113	100	100	27.4	100	100	/		/	
	4	2	50x2	1,620	100		106.57	100		187	100		27.4	100		/		/	
	5	2	50x2	1,620	100		266.42	100		160	100		66.8	100		/		/	
E	1	4	40x4 (2 Luff)	11,102	100		553.50	100		233	100		63.2	100				/	
	2	4	40x4 (3 Luff)	10,697	96.4		235.44	97.3		146.2	93.1		54.0	100		/			
	3	2	50x3 (2 Luff)	10,368	93.4	97.3	194.40	100	99.5	166	100	98.6	0.0	0	60	/		/	
	4	4	40x3 (3 Luff), 50x1	10,751	96.8		270.00	100		176	100		0.0	0		/		/	
	5	5	30x1 (Luff), 40x4	11,102	100		160.65	100		318	100		13.5	100		/		/	
				Average	96.7			97.5			97.3			60.0					

Table B22 shows the summed indices of the efficiency of tower cranes' rotations and types of tower cranes

Site	Ex-pert	Number of Tower cranes	Type	Efficiency of tower cranes if it is specified as fixed at the same position in the layout														
				1			2			3			4			5		
				% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane
A	1	1	60x1	86.7	Fixed													
	2	2	50x2	57.8	Fixed		65.3	Fixed										
	3	1	60x1	86.7	Fixed													
	4	2	50x2	53.9	Fixed		100.0	Fixed	-									
	5	2	50x2	35.8	Fixed		100.0	Fixed	-									
B	1	1	50x1	83.6	Fixed	/												
	2	1	40x1	87.8	Fixed	/												
	3	1	40x1 (Luff)	51.7	Luff													
	4	1	50x1	87.2	Fixed	/												
	5	1	50x1 (Luff)	20.3	Luff	/												
C	1	2	40x2	100.0	Fixed	-	100.0	Fixed	-									
	2	2	40x2	100.0	Fixed	-	100.0	Fixed	-									
	3	2	35x1, 50x1	63.3	Fixed		100.0	Fixed	/									
	4	3	40x2 (Luff), 50x1	100.0	Fixed	-	52.8	Luff		52.8	Luff							
	5	3	40x2 (Luff), 40x1	61.1	Luff	/	100.0	Fixed	-	58.1	Luff							

Table B22 (Continued) shows the summed indices of the efficiency of tower cranes’ rotations and types of tower cranes

Site	Ex-pert	Number of Tower cranes	Type	Efficiency of tower cranes if it is specified as fixed at the same position in the layout														
				1			2			3			4			5		
				% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane	% Swing	Type of the tower crane	Has necessity to travel to the back side of the tower crane
D	1	2	50x2	100.0	Fixed	-	100.0	Fixed	-									
	2	2	50x2	100.0	Fixed	-	100.0	Fixed	-									
	3	2	50x2	100.0	Fixed	-	100.0	Fixed	-									
	4	2	50x2	100.0	Fixed	-	100.0	Fixed	-									
	5	2	50x2	100.0	Fixed	-	100.0	Fixed	-									
E	1	4	40x4 (2 Luff)	49.4	Luff	/	61.7	Luff	/	52.8	Fixed		100.0	Fixed	-			
	2	4	40x4 (3 Luff)	80.6	Luff	/	50.3	Luff	/	58.6	Fixed		43.1	Luff	/			
	3	2	50x3 (2 Luff)	50.0	Luff	/	72.2	Luff	/	34.7	Fixed							
	4	4	40x3 (3 Luff), 50x1	52.5	Luff	/	40.8	Fixed	/	67.8	Luff	/	50.6	Luff				
	5	5	30x1 (Luff), 40x4	52.2	Fixed		45.6	Luff	/	38.1	Fixed		38.6	Fixed		42.8	Fixed	

The swing radius of **fixed** tower cranes	80.70	%		The swing radius of **luffing** tower cranes	54.13	%
Lowest	34.72	%		Lowest	20.28	%
Number	38	units		Number	17	units
SD	24.19	%		SD	25.86	%

Table B23 shows the type of the tower cranes’ installing and the distance from the building if the tower cranes are attached to the building

Site	Expert	Number of Tower cranes	Type	Distance between attached tower cranes and building									
				1		2		3		4		5	
				Type of the installing	Distance from the building (m.)	Type of the installing	Distance from the building (m.)	Type of the installing	Distance from the building (m.)	Type of the installing	Distance from the building (m.)	Type of the installing	Distance from the building (m.)
A	1	1	60x1	IB	-								
	2	2	50x2	IB	-	IB	-						
	3	1	60x1	IB	-								
	4	2	50x2	AB	3.2	AB	4.48						
	5	2	50x2	AB	3.84	IB	-						
B	1	1	50x1	AB	2.1								
	2	1	40x1	IB	-								
	3	1	40x1 (Luff)	BB	-								
	4	1	50x1	AB	3								
	5	1	50x1 (Luff)	AB	3.9								
C	1	2	40x2	BB	-	IB	-						
	2	2	40x2	BB	-	IB	-						
	3	2	35x1, 50x1	AB	4.59	IB	-						
	4	3	40x2 (Luff), 50x1	BB/AB	2.92	AB	2.92	AB	2.92				
	5	3	40x2 (Luff), 40x1	AB	2.50	IB	-	BB	-				

Table B23(Continued) shows the type of the tower cranes' installing and the distance from the building if the tower cranes are attached to the building

Site	Expert	Number of Tower cranes	Type	Distance between attached tower cranes and building									
				1		2		3		4		5	
				Type of the installing	Distance from the building (m.)	Type of the installing	Distance from the building (m.)	Type of the installing	Distance from the building (m.)	Type of the installing	Distance from the building (m.)	Type of the installing	Distance from the building (m.)
D	1	2	50x2	IB	-	IB	-						
	2	2	50x2	IB	-	IB	-						
	3	2	50x2	IB	-	IB	-						
	4	2	50x2	AB	4.35	AB	4.35						
	5	2	50x2	AB	2.18	AB	2.18						
E	1	4	40x4 (2 Luff)	IB	-	IB	-	IB	-	IB	-		
	2	4	40x4 (3 Luff)	IB	-	IB	-	IB	-	IB	-		
	3	2	50x3 (2 Luff)	IB	-	IB	-	IB	-				
	4	4	40x3 (3 Luff), 50x1	AB	2.6	IB	-	AB	1.56	IB	-		
	5	5	30x1 (Luff), 40x4	IB	-	AB	3.12	IB	-	IB	-	IB	-

Average distance AB = 3.15 m. Legends: IB = Inside the building AB = Attached to the building BB = Blocked in the building

Table B24 shows the type of the tower cranes' installing with sizes

Site	Expert	Number of Tower cranes	Type	Position			
				Lift Core	Attach to the building (Vertically straight)	Block the floor (Vertically straight)	Separate from the building (Vertically straight)
A	1	1	60x1	1			
	2	2	50x2	2			
	3	1	60x1	1			
	4	2	50x2		2		
	5	2	50x2	1	1		
	Average	1.6	Sum	5	3	0	0
B	1	1	50x1		1		
	2	1	40x1	1			
	3	1	40x1 (Luff)			1	
	4	1	50x1		1		
	5	1	50x1 (Luff)		1		
	Average	1	Sum	1	3	1	0
C	1	2	40x2	1		1	
	2	2	40x2	1		1	
	3	2	35x1, 50x1	1 (35 m.)	1 (50 m.)		
	4	3	40x2 (Luff), 50x1		3		
	5	3	40x2 (Luff), 40x1	1	1	1	
	Average	2.4	Sum	4	5	3	0
D	1	2	50x2	2			
	2	2	50x2	2			
	3	2	50x2	2			
	4	2	50x2		2		
	5	2	50x2		2		
	Average	2	Sum	6	4	0	0
E	1	4	40x4 (2 Luff)	4			
	2	4	40x4 (3 Luff)	4			
	3	2	50x3 (2 Luff)	3			
	4	4	40x3 (3 Luff), 50x1		2	2 (50 m.x1)	
	5	5	30x1 (Luff), 40x4		1 (30 m.)	4	
	Average	3.8	Sum	11	3	6	0

Table B25 shows the type of the distance between the building and the concrete pump

Site	Type of the building	Expert	Concrete pump properties						
			Static				Mobile		
			Furthest distance of the building from the pump	Distance from the pump to the joint bending to the upper floors	Horizontal Bending	Location of the concrete pipe	Longest shooting distance	The mobile pump can travel inside the site	The mobile pump has to shoot from outside
Site A	International Office	1	73.6	14.72	1	Mechanical Shaft	-	-	-
		2	77.44	0	0	Prefab wall	-	-	-
		3	-	-	-	-	70.4	Yes	No
		4	73.6	0	0	Prefab wall	-	-	-
		5	60.8	3.84	0	Prefab wall	-	-	-
Site B	Multipurpose Building	1	52.5	10.5	1	Prefab wall	-	-	-
		2	57	0	0	Prefab wall	-	-	-
		3	49.5	3.6	1	Prefab wall	-	-	-
		4	52.5	3	0	Prefab wall	-	-	-
		5	52.5	3	0	Prefab wall	-	-	-
Site C	Office and Shopping Mall	1	39.615	18.765	0	Stairs core	-	-	-
		2	25.854	18.765	1	Lift core	-	-	-
		3	29.19	29.19	1	Lift core	-	-	-
		4	60.465	3.336	0	Masonry Wall	-	-	-
		5	25.854	19.599	2	Lift core	-	-	-
Site D	Dorm	1	-	-	-	-	26.1	No	Yes
		2	-	-	-	-	43.5	No	Yes
		3	-	-	-	-	47.85	No	Yes
		4	-	-	-	-	47.85	No	Yes
		5	52.2	2.175	0	Prefab wall	-	-	-
Site E	Shopping Mall	1	-	-	-	-	65	No	Yes
		2	-	-	-	-	65	No	Yes
		3	-	-	-	-	65	No	Yes
		4	-	-	-	-	65	No	Yes
		5	-	-	-	-	65	No	Yes
		Average	48.91	8.16	0.44		50.97		

Appendix C

Validation of rule bases

Remark: “Reference” means the reference of the interested fact, came from the analysis of the corresponding tables or figures in Appendix A and B

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score					Average	Code
						A	B	C	D	E		
Design of the building	Tower crane	A46	Tower crane ไม่สามารถเคลื่อนที่ผ่าน Tower crane ที่มีความสูงมากกว่าได้	เมื่อความสูงของ Tower crane ตัวที่สนใจสูงน้อยกว่า Tower crane ตัวอื่น	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้น	5	5	5	5	5	5	1
		B1	ควรติดตั้ง Tower crane ที่ ผนัง Prefab ก่อน Masonry wall	เมื่อเลือกสถานที่ที่ตั้ง Tower crane เป็นด้านข้างอาคารและมีผนังที่มี Finishing เป็น Prefab ให้เลือก	เพื่อให้ลดขั้นตอนการเก็บงาน	3	5	3	5	4	4	2
		B1	ควรติดตั้ง Tower crane ที่ Masonry wall	เมื่อเลือกสถานที่ที่ตั้ง Tower crane เป็นด้านข้างอาคารและไม่มีผนังที่มี Finishing เป็น Prefab ให้เลือก	เพื่อให้สามารถทำงานได้	3	5	3	5	4	4	3
		B1	ควรหลีกเลี่ยงการติดตั้ง Tower crane ที่กระจก	เมื่อเลือกสถานที่ที่ตั้ง Tower crane เป็นด้านข้างอาคาร	เพื่อป้องกันความเสียหายที่จะเกิดขึ้นกับงาน	5	5	5	5	4	5	4
		B1, B21	Tower crane ควรจะครอบคลุมพื้นที่ของอาคารและ Storage มากกว่า 97%		เพื่อให้เกิดความคุ้มค่าในการปฏิบัติงาน	4	5	5	5	5	5	5
		Case D	วาง Tower crane ให้สมมาตร	เมื่ออาคารที่ก่อสร้างเป็นรูปสมมาตร	เพื่อให้เกิดความคุ้มค่าในการปฏิบัติงาน	5	5	5	5	4	5	6
	Concrete pump	B25	ระยะทางไกลจากอาคารถึงสถานที่ที่ท่อส่งคอนกรีตอยู่ควรจะไม่เกิน 50 ม.	เมื่อมีการใช้ Concrete pump แบบ Stationary ในสถานที่	การทำงานของ Concrete pump ควรจะสามารถครอบคลุมบริเวณ	5	5	3	5	5	5	7

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score					Ave rage	Code
						A	B	C	D	E		
				ก่อสร้าง	อาคารที่ก่อสร้างให้ได้มากที่สุด เพื่อให้สามารถทำงานได้คุ้มค่า							
		B25	ระยะทางจากอาคารถึงสถานที่ที่ Mobile concrete pump สามารถเข้าถึงได้ใกล้ที่สุดควรจะไม่เกิน 50 ม.	เมื่อมีการใช้ Concrete pump แบบ Mobile ในสถานที่ก่อสร้าง	การทำงานของ Concrete pump ควรจะสามารถครอบคลุมบริเวณอาคารที่ก่อสร้างให้ได้มากที่สุด เพื่อให้สามารถทำงานได้คุ้มค่า	5	5	2	5	5	5	8
		B3, B25	ควรจะมีช่องเปิด เช่น Lift core, Stair core, หรือ Mechanical Shaft ให้ท่อของคอนกรีตสามารถทะลุขึ้นไปสู่ชั้นต่างๆได้	เมื่อมีการใช้ Concrete pump แบบ Stationary ในสถานที่ก่อสร้าง	เพื่อให้สามารถทำงานได้	1	5	2	5	5	5	9
Design of the building/Site constraints		B3, B25	ท่อของ Concrete pump สามารถติดตั้งกับข้างอาคารเพื่อขึ้นไปสู่ชั้นสูงๆได้	เมื่อ Concrete pump เป็นแบบ Stationary และอาคารที่ก่อสร้างน้อยกว่า 70 เมตร	เพื่อให้สามารถทำงานได้	5	3	2	5	5	5	10
Design of the building		B3, B25	ควรติดตั้งท่อของ Concrete pump ที่ Prefab	เมื่อ Concrete pump เป็นแบบ Stationary, เลือกสถานที่ที่ท่อคอนกรีตผ่านเป็นด้านข้างอาคาร และมีผนังที่มี Finishing เป็น Prefab ให้เลือก	เพื่อให้ลดขั้นตอนการเก็บงาน	5	5	4	5	5	5	11

Dominances	Target components	Reference	Relationships	Conditions	Reasons	Score					Average	Code
						A	B	C	D	E		
		B3, B25	ควรติดตั้งท่อของ Concrete pump ที่ Masonry wall	เมื่อ Concrete pump เป็นแบบ Stationary, เลือกสถานที่ที่ท่อคอนกรีตผ่านเป็นด้านข้างอาคาร และไม่มีผนังที่มี Finishing เป็น Prefab ให้เลือก	เพื่อให้สามารถทำงานได้	5	5	4	5	5	5	12
Design of the building/Method of work		B3, B25	ควรจะหลีกเลี่ยงการติดตั้งท่อของ Concrete pump ที่กระจก	เมื่อ Concrete pump เป็นแบบ Stationary และเลือกสถานที่ที่ท่อคอนกรีตผ่านเป็นด้านข้างอาคาร	เพื่อป้องกันความเสียหายที่จะเกิดขึ้นกับงาน	5	5	5	5	5	5	13
Design of the building		B25	ระยะทางจากจุดที่ท่อส่งคอนกรีตขึ้นไปตามอาคารควรจะห่างไม่เกิน 30 เมตรจาก Concrete pump	เมื่อ Concrete pump เป็นแบบ Stationary	เพื่อให้สามารถทำงานได้ อย่างไรก็ดีควรจะมีการคำนวณเรื่องแรงดันของปั๊มด้วยว่ามีกำลังส่งเท่าใดและสามารถส่งถึงที่หมายได้หรือไม่	5	5	2	5	5	5	14
	Passenger lifts	B5, B18	ควรจะมี Passenger lift อย่างน้อย 1 จุด 1 ตัว	เมื่ออาคารสูงกว่า 23 เมตร หรือ 7 ชั้น	เพื่อสนับสนุนการทำงานของแรงงานให้ได้ Productivity มากขึ้น	5	5	5	5	5	5	15
		B18	ควรมี Passenger lift อย่างน้อย 2 จุด	เมื่ออาคารมีขนาดด้านยาวมากกว่าด้านกว้าง 2 เท่า หรือ มีขนาดพื้นที่ต่อชั้นกว้างกว่า	เพื่อสนับสนุนการทำงานของแรงงานให้ได้ Productivity มากขึ้น	1	5	5	5	5	5	16

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score					Average	Code
						A	B	C	D	E		
				10,000 ตร.ม.								
		B18	ควรมี Passenger lift เพิ่ม 1 ตัว	เมื่อมีพื้นที่ปฏิบัติงานต่อชั้นที่ลิฟต์ควรจะครอบคลุมทุกๆ 2,000 ตร.ม.	เพื่อสนับสนุนการทำงานของแรงงานให้ได้ Productivity มากขึ้น	2	4	4	3	4	4	17
		B18	ควรมี Passenger lift เพิ่ม 1 ตัว	เมื่อมีพื้นที่ปฏิบัติทุกชั้นที่ลิฟต์ควรจะครอบคลุมทุกๆ 30,000 ตร.ม.	เพื่อสนับสนุนการทำงานของแรงงานให้ได้ Productivity มากขึ้น	2	5	5	3	4	4	18
		B5, B18	ควรติดตั้ง Passenger lifts ที่ Prefab	เมื่อมีการใช้งาน Passenger liftและมีผนังที่มี Finishing เป็น Prefab ให้เลือก	เพื่อให้ลดขั้นตอนการเก็บงาน	5	5	5	5	5	5	19
Design of the building/Method of work		B5, B18	ควรติดตั้ง Passenger lifts ที่ Masonry wall	เมื่อมีการใช้งาน Passenger liftและไม่มีผนังที่มี Finishing เป็น Prefab ให้เลือก	เพื่อให้สามารถทำงานได้	5	5	5	5	3	5	20
Design of the building		B5, B18	ควรจะหลีกเลี่ยงการติดตั้ง Passenger lifts ที่กระจก	เมื่อมีการใช้งาน Passenger lifts	เพื่อป้องกันความเสียหายที่จะเกิดขึ้นกับงาน	5	5	5	5	5	5	21
		B18	ควรติดตั้ง Passenger lifts ให้แรงงานเดินไม่ไกลกว่า 100 เมตร เมื่อเดินออกจากลิฟต์ถึงจุดที่ไกลสุดของอาคาร		เพื่อสนับสนุนการทำงานของแรงงานให้ได้ Productivity มากขึ้น	5	5	4	5	5	5	22

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score					Average	Code
						A	B	C	D	E		
		B18	ควรจะติดตั้ง Passenger lifts ในที่ๆ สามารถวิ่งยาวได้ตลอดความสูงอาคาร		เพื่อสนับสนุนการทำงานของแรงงานให้ได้ Productivity มากขึ้น	5	4	5	5	5	5	23
	Mobile cement plant	B4	ควรจะมีปริมาณคอนกรีตที่ใช้มากกว่า...		เพื่อความคุ้มค่าในการใช้ Mobile cement plant							24
Component constraints	Tower crane	A45	Tower crane สามารถถูกติดตั้งโดยไม่ควรจะยึดเกาะกับอาคารได้	เมื่อเป็นอาคารที่สูงไม่เกิน 23 เมตร	การติดตั้ง Tower crane ชนิดนี้สามารถทำได้กับงานก่อสร้างอาคารที่มีขนาดไม่สูงมาก มีค่าใช้จ่ายในการทำฐานรากและ Mast ที่ควรจะใช้ในการติดตั้ง Tower crane	5	5	4	5	5	5	25
		A45	Tower crane สามารถถูกติดตั้งภายในช่องเปิดของอาคารเช่น Lift core และ Stairs core		ช่องเปิดของอาคารช่วยประหยัดค่าใช้จ่ายในเรื่องของการทำฐานราก Tower crane เนื่องจากสามารถใช้ฐานรากของ Core เป็นฐานรากของ Tower crane ได้เช่นกัน นอกจากนี้ยังสามารถประหยัดค่าใช้จ่ายโดยการใช้ Climbing crane เพื่อลดปริมาณ Mast ที่ควรจะใช้ในการตั้ง Tower crane อีกด้วย	5	5	5	5	5	5	26

Dominances	Target components	Reference	Relationships	Conditions	Reasons	Score					Average	Code
						A	B	C	D	E		
		A45	Tower crane สามารถถูกติดตั้งเข้ากับด้านข้างอาคารได้		การติดตั้งข้างอาคารทำให้สามารถติดตั้งและถอดการติดตั้งได้รวดเร็ว ฐานรากอาจควรจะมีการดัดแปลงซึ่งเกิดค่าใช้จ่ายบ้าง	5	5	5	5	5	5	27
		A45	Tower crane สามารถถูกติดตั้งโดยการเจาะพื้นอาคารและตั้งในอาคาร		การติดตั้ง Tower crane ชนิดนี้ทำให้เกิดค่าใช้จ่ายสูงและจำเป็นควรจะเก็บงานซึ่งอาจทำให้ล่าช้า จึงควรเลือกวิธีนี้เมื่อไม่มีวิธีการติดตั้ง Tower crane ที่สามารถครอบคลุมพื้นที่เป้าหมายได้ทั้งหมด	5	5	5	5	5	5	28
		B24	Tower crane ควรเลือกติดที่ภายใน Core ของอาคารก่อน จากนั้นจึงเป็นติดตั้งข้างอาคาร และเจาะพื้นตามลำดับ		เพื่อให้เกิดความคุ้มค่าในการปฏิบัติงาน	2	5	5	3	3	3	29
		B22	Tower crane ควรเป็นแบบ Fixed	เมื่อสามารถหมุนได้มากกว่า 80% ของระยะการหมุน ณ ตำแหน่งนั้นหรืออย่างน้อยไม่น้อยกว่า 50%	เพื่อให้เกิดความคุ้มค่าในการปฏิบัติงาน	5	5	5	5	5	5	30
		B22	Tower crane ควรเป็นแบบ Luffing	เมื่อสามารถหมุนได้มากกว่า 50% ของระยะการหมุน	เพื่อให้เกิดความคุ้มค่าในการปฏิบัติงาน	5	5	5	5	5	5	31

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score					Average	Code
						A	B	C	D	E		
				ณ ตำแหน่งนั้น หรืออย่างน้อยไม่น้อยกว่า 20%								
		B22	Tower crane แต่ละตำแหน่ง ควรจะหมุนได้ไม่ต่ำกว่า 20% ของระยะการหมุน ณ ตำแหน่งนั้น		เพื่อให้เกิดความคุ้มค่าในการปฏิบัติงาน	5	5	5	5	5	5	32
		B23	Tower crane ควรจะอยู่ห่างจากตัวอาคารไม่น้อยกว่า 2 เมตรและไม่เกิน 6 เมตร	เมื่อใช้วิธีการติดตั้ง Tower crane แบบติดตั้งข้างอาคาร	เพื่อให้สามารถปฏิบัติงานได้	5	2	5	5	4	5	33
		B24	Tower crane ควรจะติดตั้งที่ๆเป็นแนวดิ่งราบตลอดอาคาร		เพื่อให้สามารถติดตั้งได้สะดวก	5	5	5	5	5	5	34
		B23	ขนาดของ Tower crane โดยปกติอยู่ที่ 30 35 40 45 และ 50 เมตร		เพื่อให้สามารถเลือกใช้ Tower crane ที่มีอยู่จริงในตลาด	5	5	5	5	5	5	35
Component constraints /Duration of the project	Site office	B6	ใช้ Site office แบบสร้างสำเร็จ	เมื่อควรจะมีการย้าย Site office เข้าไปด้านในสถานที่ก่อสร้างหรือมีระยะเวลาโครงการน้อยกว่า 2 ปี	เพื่อให้เกิดความคุ้มค่าในการปฏิบัติงาน	5	5	5	5	5	5	36
Component constraints		B6	ใช้ Site office แบบสร้างใหม่	เมื่อไม่ควรจะมีการย้าย Site office เข้าไปด้านในสถานที่ก่อสร้าง เวลาโครงการนานกว่า 2 ปี และไม่มี Site office แบบสร้างสำเร็จอยู่	เพื่อให้สามารถปฏิบัติงานได้	5	5	5	5	5	5	37

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score					Ave rage	Code
						A	B	C	D	E		
		B6	สามารถใช้ Site office แบบสร้างสำเร็จหรือสร้างใหม่ก็ได้	เมื่อมี Site office แบบสร้างสำเร็จอยู่แล้ว และระยะเวลาก่อสร้างเกิน 2 ปี	เพื่อให้สามารถปฏิบัติงานได้	5	5	5	5	5	5	38
	Toilet	B9	ห้องน้ำวิศวกรควรแยกห่างจากห้องน้ำแรงงาน ถ้าเป็นไปได้	เมื่อ Site office เป็นแบบสร้างสำเร็จ	เพราะห้องน้ำของแรงงานมีกลิ่นและดูแลรักษาความสะอาดยากกว่า	5	5	5	5	5	5	39
		B10,	โดยเฉลี่ยขนาดห้องน้ำอยู่ที่ 7 ตร.ม.		เพื่อให้สามารถใช้งานได้	1	2	1	1	4	1	40
	Concrete pump	B3	Concrete pump จำนวน 1 เครื่องเพียงพอต่อการทำงาน		เพื่อให้เกิดความคุ้มค่าในการปฏิบัติงาน	5	5	5	5	5	5	41
		B25	ไม่ควรมีจุดหักแนวราบของท่อคอนกรีตมากกว่า 1 ครั้ง	เมื่อ Concrete pump เป็นแบบ Stationary	เพื่อไม่ให้สูญเสียแรงดันของคอนกรีตเกินความจำเป็น	5	5	5	4	5	5	42
Component availability	Passenger lifts	Case A1, Case A3	พิจารณาจากเครื่องจักรที่มีอยู่ก่อน		เพื่อประหยัดค่าใช้จ่ายที่เกิดจากการซื้อหรือเช่า	5	5	5	5	5	5	43
	Tower crane	Case A1, Case A3	พิจารณาจากเครื่องจักรที่มีอยู่ก่อน		เพื่อประหยัดค่าใช้จ่ายที่เกิดจากการซื้อหรือเช่า	5	5	5	5	5	5	44
	Concrete pump	Case A1, Case A3	พิจารณาจากเครื่องจักรที่มีอยู่ก่อน		เพื่อประหยัดค่าใช้จ่ายที่เกิดจากการซื้อหรือเช่า	5	5	5	5	5	5	45
	Site office	Case A1, Case A3	พิจารณาจากวัสดุที่มีอยู่ก่อน		เพื่อประหยัดค่าใช้จ่ายที่เกิดจากการซื้อหรือเช่า	5	5	5	5	5	5	46
	Store	Case A1, Case A3	พิจารณาจากวัสดุที่มีอยู่ก่อน		เพื่อประหยัดค่าใช้จ่ายที่เกิดจากการซื้อหรือเช่า	5	5	5	5	5	5	47

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score					Average	Code
						A	B	C	D	E		
Components' relationship on the site	Mobile cement plant & Concrete pump	Case A3	Concrete pump ควรตั้งใกล้กับ Mobile cement plant	เมื่อมีการใช้ Mobile cement plant ในสถานที่ก่อสร้าง	เพื่อสนับสนุนการทำงานให้ได้ Productivity มากขึ้น	5	5	2	1	1	2	48
	Mobile cement plant & Site office	B4, B6	Site office ควรถูกย้ายมาไว้ด้านหลังสถานที่ก่อสร้าง	เมื่อมีการใช้งาน Mobile cement plant	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้นจากรถบรรทุกปูนที่ควรจะขับไปมาในสถานที่ก่อสร้าง	3	5	3	5	1	3	49
	Site office & Toilet	B10, Site investigation	ห้องน้ำของ Staff ควรจะอยู่ภายใน Site office โดยมีห้องน้ำอย่างน้อย 2-4 ห้อง	เมื่อ Site office เป็นแบบสร้างใหม่	เพื่อสนับสนุนการทำงานของ Staff เนื่องจากไม่จำเป็นควรจะเดินออกจาก Site office เพื่อเข้าห้องน้ำ	5	5	5	5	5	5	50
	Site office & Toilet	Site investigation	ห้องน้ำวิศวกรควรจะอยู่ใกล้ Site office ระยะไม่เกิน 50 ม.	เมื่อ Site office เป็นแบบสร้างสำเร็จ	เพื่อสนับสนุนการทำงานของ Staff เนื่องจากไม่จำเป็นควรจะเดินออกจาก Site office ไกลๆ เพื่อเข้าห้องน้ำ	5	4	5	5	4	5	51
	Passenger lifts & Toilet	B9	ห้องน้ำควรจะไม่อยู่ติดกับ Passenger lifts		เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้น	3	5	5	5	5	5	52
	Tower crane & Steel yard	B7, B21	Steel yard ควรจะอยู่ในรัศมี Tower crane		Tower crane สามารถสนับสนุนการทำงานได้	5	5	5	5	5	5	53
	Tower crane & Laydown area	B2, B21	Laydown area ควรจะอยู่ในรัศมี Tower crane		Tower crane สามารถสนับสนุนการทำงานได้	5	5	5	5	5	5	54
	Tower crane & Toilet	B1, B9, B21	ห้องน้ำควรอยู่ห่างจากรัศมีของ Tower crane	เมื่อมีพื้นที่ที่สามารถตั้งห้องน้ำได้นอกรัศมีของ Tower crane	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้น	5	5	5	5	5	5	55

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score					A ve ra ge	Cod e
						A	B	C	D	E		
	Tower crane & Store	B8, B21	Store ควรจะอยู่ในรัศมี Tower crane	เมื่อรถบรรทุกไม่สามารถเข้าถึง Store ได้	Tower crane สามารถส่งของจากรถบรรทุกเข้าสู่ Store ได้	5	5	1	4	2	4	56
	Entrance gate & Traffic on the site	B15	กำหนดให้เป็นทางเข้าทางหนึ่ง ทางออกอีกทางหนึ่ง	ในกรณีที่รถบรรทุกกลับรถได้ลำบากและมีทางเข้าออกสถานที่ก่อสร้าง 2 ทาง	เพื่อให้การจราจรในสถานที่ก่อสร้างมีความคล่องตัว	1	5	5	5	5	5	57
	Site office & Store	B8	Store ควรอยู่ใกล้ Site office		เพื่อให้ Store สามารถติดต่อประสานงานกับ Site office ได้สะดวก	1	5	5	1	4	4	58
	Site office & Staff's Door	B6, B13	ควรมีประตู Staff เพื่อให้ Staff สามารถเข้าออกสถานที่ก่อสร้างได้โดยง่ายและไม่ควรจะเดินผ่านสถานที่ก่อสร้างเป็นระยะทางไกลๆ	เมื่อมีการตั้ง Site office ติดกับมุมอื่นที่อยู่ไกลจากประตูทางเข้าออกหลักและทางเดินที่ควรจะใช้เพื่อเดินทางผ่านมีอันตราย เช่น Tower crane หรือรถบรรทุกเคลื่อนที่ผ่าน	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้น	1	5	1	5	2	2	59
Components' relationship on the site/Traffic on the site	Entrance gate & Laydown area	B13	Laydown area ควรจะถูกวางติดกับ Entrance gate	ถ้า Traffic on the site รถบรรทุกไม่สามารถเข้าสู่พื้นที่ด้านในสถานที่ก่อสร้างได้	เพิ่ม Productivity ในการขนส่ง	5	5	5	5	5	5	60
Type of the building	Site protection	B15	ควรจะมีการทำหลังคากันของตกลงสู่เบื้องล่างทุกด้านของอาคาร	ในกรณีที่เป็นอาคารที่สูงกว่า 150 เมตร	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้น	5	4	5	5	4	5	61

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score					Average	Code
						A	B	C	D	E		
Type of the building	Concrete pump	B3	ควรจะมีการใช้ Concrete pump	เมื่ออาคารที่ก่อสร้างเป็นอาคารสูง ในเขตเมือง	เพื่อสนับสนุนการทำงานให้ได้ Productivity มากขึ้น	5	5	5	5	5	5	62
Location of the site	Site protection	B15	ควรจะมีการทำหลังคาป้องกันด้านที่มีผู้คนเดินผ่านพลุกพล่านหรือมีรถขับผ่าน	ในกรณีที่ด้านข้างสถานที่ก่อสร้างมีผู้คนเดินผ่านหรือมีรถขับผ่าน	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้น	5	5	5	5	5	5	63
Location of the site	Laydown area	B2	สามารถให้รถบรรทุกจอดส่งของจากด้านนอกได้	ถ้า Traffic on the site รถบรรทุกไม่สามารถเข้าสู่สถานที่ก่อสร้างได้ และ พื้นที่ด้านนอกสามารถจอดรถได้	เพื่อให้สามารถทำงานได้	5	5	5	4	5	5	64
		B2, B3	ให้รถบรรทุกจอดส่งของจากด้านนอกโดยควรจะมีการติดต่อประสานงานกับทางตำรวจจราจรเพื่ออำนวยความสะดวกและอาจควรจะมีการวางแผนเรื่องเวลาขนส่งเป็นเวลากลางคืน	ถ้า Traffic on the site รถบรรทุกไม่สามารถเข้าสู่สถานที่ก่อสร้างได้ และ พื้นที่ด้านนอกไม่สามารถจอดรถได้	เพื่อให้สามารถทำงานได้	5	5	5	5	5	5	65
	Toilet	B9	ห้องน้ำควรตั้งอยู่ติดกับ Man Holes	เมื่อมี Man Holes อยู่ข้างๆสถานที่ก่อสร้าง	เพื่อให้สะดวกต่อการวางท่อสาธารณูปโภค	5	5	5	4	5	5	66
	Mobile cement plant	B4	ควรมีการใช้ Mobile cement plant	เมื่อการจราจรรอบสถานที่ก่อสร้างควรมีความติดขัดหรือไม่สะดวกในการขนส่ง	เพื่อขจัดปัญหาการส่งคอนกรีตล่าช้าและทำให้การเทคอนกรีตไม่ต่อเนื่อง ทำให้สามารถเทคอนกรีตได้ทุกเวลาและมีราคาประหยัดมากขึ้น	3	5	5	5	5	5	67

Dominances	Target components	Reference	Relationships	Conditions	Reasons	Score A	Score B	Score C	Score D	Score E	Average	Code
Nearby environment	Mobile cement plant	B4	ถ้ามีอาคารที่มีผู้ใช้งานอยู่เป็นสิ่งแวดล้อมรอบข้างห้ามตั้ง Mobile cement plant		ฝุ่นที่เกิด Mobile cement plant สามารถรบกวนเพื่อนบ้านได้	5	5	5	5	5	5	68
		B4	Mobile cement plant ควรอยู่ที่ด้านหน้าของสถานที่ก่อสร้าง	เมื่อมีการใช้ Mobile cement plant	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้นกับแรงงานและวิศวกรจากรถบรรทุกที่มาส่งวัสดุและควรจะขนส่งคอนกรีตไปยังหน้างาน	3	5	3	1	1	3	69
	Toilet	Site investigation	ห้องน้ำของแรงงานไม่ควรตั้งอยู่ติดกำแพงด้านที่มีคนอยู่หรือคนพลุกพล่าน	เมื่อสิ่งแวดล้อมรอบข้างมีผู้อยู่อาศัยอยู่ หรือผู้คนเดินผ่าน	เพื่อป้องกันกลิ่นไม่พึงประสงค์ออกไปภายนอกสถานที่ก่อสร้าง	5	4	5	4	5	5	70
Nearby environment	Tower crane	B1, B22	Tower crane ควรจะระวังการหมุน ไม่ให้หมุนถูกอาคารที่มีความสูงมากกว่า Tower crane	เมื่อสิ่งแวดล้อมรอบข้างสูงกว่าความสูง Tower crane	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้น	5	5	5	5	5	5	71
		B22	Tower crane ควรจะเป็นแบบ Luffing	เมื่อมีความจำเป็นที่ Tower crane ณ ตำแหน่งนั้นควรจะผ่านพื้นที่ระหว่างตำแหน่งและสิ่งแวดล้อมรอบข้างที่เป็นอาคารบ้านเรือน	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้นและทำให้สามารถทำงานได้	5	5	5	5	5	5	72
Trucks accessiblity	Steel yard	B7	รถบรรทุกควรเข้าถึง Steel yard ได้	รถบรรทุกสามารถเข้าสู่ด้านในของสถานที่ก่อสร้างได้	เพื่อให้สามารถขนส่งเหล็กเสริมได้โดยสะดวก	3	5	5	5	5	5	73
	Laydown area	B2	รถบรรทุกควรจะสามารถเข้าถึง Laydown area ได้		เพิ่ม Productivity ในการขนส่ง	3	5	5	5	5	5	74

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score A	Score B	Score C	Score D	Score E	Average	Code
	Mobile cement plant	B4	รถบรรทุกควรจะเข้าถึง Mobile cement plant ได้		รถบรรทุกควรจะเข้าถึง Mobile cement plant เพื่อให้สามารถทำงานได้	5	5	5	5	5	5	75
	Store	B8	Store ควรอยู่ในบริเวณที่รถบรรทุกเข้าถึงได้	เมื่อรถบรรทุกสามารถเข้าสู่พื้นที่ภายในสถานที่ก่อสร้างได้	เพื่อให้สามารถขนส่งวัสดุอุปกรณ์และเครื่องมือได้สะดวก	1	5	5	4	5	5	76
	Concrete pump	B3	รถบรรทุกคอนกรีตควรจะสามารถเข้าถึง Concrete pump ได้	เมื่อ Concrete pump เป็นแบบ Stationary	เพื่อสนับสนุนการทำงาน	5	5	5	5	5	5	77
Free space	Steel yard	B7	หลักการจัดการ Steel yard ใช้วิธีการสำรองเป็นรอบงาน	หากมีพื้นที่ว่างต่ำกว่า 2000 ตร.ม. ลงมาภายในสถานที่ก่อสร้าง	เพื่อให้สามารถบริหารจัดการพื้นที่ให้เกิดประโยชน์สูงสุด	5	5	2	5	5	5	78
		B7	หลักการจัดการ Steel yard ใช้วิธีการสำรองทีละมากๆ	หากมีพื้นที่ว่างสูงกว่า 6800 ตร.ม. ขึ้นไปภายในสถานที่ก่อสร้าง	เพื่อให้สามารถสั่งซื้อได้ในราคาที่ถูกลง	1	5	2	4	1	2	79
	Mobile cement plant	B4	ควรจะมีพื้นที่เหลือมากกว่า...		เพื่อให้สามารถบริหารจัดการพื้นที่ให้เกิดประโยชน์สูงสุด							80
	Toilet	B9	ห้องน้ำควรถูกตั้งในตำแหน่งลับตาผู้มาติดต่อ	เมื่อมีพื้นที่ที่สามารถตั้งห้องน้ำให้หลบสายตาผู้มาติดต่อได้	เพื่อสร้างภาพลักษณ์ที่ดีแก่ผู้มาติดต่อ	5	5	5	5	4	5	81
	Store	B8, B19	เลือกใช้ Store เป็นแบบสร้างสำเร็จ ขนาดของ Store พิจารณาจากขนาดของตู้คอนเทนเนอร์แบบสร้างสำเร็จ (2.5 x 6 ม.)	เมื่อควรจะมีการย้าย Store เข้าไปด้านในอาคารเมื่อก่อสร้างไปในระดับหนึ่ง	เพื่อให้ใช้ได้ชั่วคราวก่อนจะย้ายเข้าไปภายในอาคาร ทำให้ได้พื้นที่ที่สามารถใช้งานได้รอบสถานที่ก่อสร้างเพิ่ม	5	2	5	5	3	5	82

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score A	Score B	Score C	Score D	Score E	Average	Code
Free space/Method of work		B8, B19	ควรมีการย้าย Store เข้าไปภายในอาคารที่กำลังก่อสร้าง	เมื่อมีพื้นที่ว่างน้อยกว่า 2000 ตร.ม. หรือ 25% ของ Site	เพื่อให้สามารถบริหารจัดการพื้นที่ให้เกิดประโยชน์สูงสุด	4	4	4	5	5	4	83
	Site office	B6, B19	ควรมีการย้าย Site office เข้าไปภายในอาคารที่กำลังก่อสร้าง	เมื่อมีพื้นที่ว่างน้อยกว่า 2000 ตร.ม. หรือ 25% ของ Site	เพื่อให้สามารถบริหารจัดการพื้นที่ให้เกิดประโยชน์สูงสุด	4	4	4	5	5	4	84
Free space		Site investigation	Site office และ Store สามารถสร้างเป็น 2 ชั้นได้	เมื่อมีพื้นที่ว่างน้อยกว่า 2000 ตร.ม. หรือ 25% ของ Site และไม่ควรจะการย้ายเข้าไปด้านในสถานที่ก่อสร้าง	เพื่อให้สามารถบริหารจัดการพื้นที่ให้เกิดประโยชน์สูงสุด	5	4	5	5	5	5	85
	Concrete pump	B3	ควรจะมีที่ว่างให้รถคอนกรีตสามารถจอดรอได้	เมื่อมีการใช้ Concrete pump ในสถานที่ก่อสร้าง	เพื่อสนับสนุนการทำงานให้ได้ Productivity มากขึ้น	5	5	5	5	5	5	86
Site constraints	Steel yard	B7	Steel yard ควรจะมีด้านหนึ่งด้านใดติดกับกำแพง		เพื่อประโยชน์ในการจัดเก็บ ไม่ขัดขวางการทำงานอื่นๆ	1	1	1	3	5	1	87
	Laydown area	B14	ขนาด Laydown area สามารถหาได้จากสูตร Laydown area เท่า 1.31% ของขนาดสถานที่ก่อสร้างบวกด้วย 115 ตร.ม		เพื่อให้สามารถบริหารจัดการพื้นที่ให้เกิดประโยชน์สูงสุด	5	5	3	3	5	5	88
	Site office	B6	Site office ควรจะไม่ตั้งอยู่ในแนว Material path	เมื่อ Material path คือเส้นทางการเคลื่อนที่ของ Material	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้น	5	5	5	5	5	5	89

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score					Ave rage	Code
						A	B	C	D	E		
				ภายในรัศมีของ Tower crane 1 ตัว จาก Storage ถึงอาคาร								
		B6	Site office ควรตั้งที่ด้านหน้าของสถานที่ก่อสร้าง	เมื่อไม่มีการใช้ Mobile cement plant ที่ด้านหน้าในสถานที่ก่อสร้างและปลอดภัยจากขนส่งของ	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้นและสะดวกต่อผู้มาติดต่อ	5	5	5	5	5	5	90
		A2	Site office ควรตั้งที่ๆสามารถอยู่ได้จนจบงานและตกแต่งเก็บงานได้ไม่ยาก เช่น สนามหญ้า, สวน	เมื่อไม่ควรจะมีการย้าย Site office เข้าไปด้านในสถานที่ก่อสร้าง	เพื่อให้เก็บงานได้สะดวกและไม่ควรจะทำการย้ายบ่อยซึ่งทำให้เกิดภาระค่าใช้จ่าย	5	5	5	5	5	5	91
	Toilet	B1, B9	Toilets ควรจะไม่ตั้งอยู่ในแนว Material path	เมื่อ Material path คือเส้นทางการเคลื่อนที่ของ Material ภายในรัศมีของ Tower crane 1 ตัว จาก Storage ถึงอาคาร	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้น	5	5	5	5	5	5	92
	Store	B20	ขนาดของ Store หาได้จากสูตร ((-0.00009*ขนาด Site^2)+(1.54*ขนาด Site))/100		เพื่อให้ได้ Store ที่มีความเหมาะสมกับขนาดสถานที่ก่อสร้าง	3	4	3	3	1	3	93
	Entrance gate	Site investigation	ใช้ทางเข้าออกอาคารเมื่อแล้วเสร็จเป็นทางเข้าออกของสถานที่ก่อสร้าง		เพื่อให้ไม่ควรจะทำเรื่องขอเปิดทางเท้าใหม่ซึ่งควรจะใช้ค่าใช้จ่ายและเวลา	2	5	5	5	5	5	94
	Site protectio	B15	ควรจะทำหลังคากันของตกลงสู่พื้น	ในกรณีที่เป็นอาคารที่สูง	เพื่อป้องกันอุบัติเหตุที่อาจ	5	5	5	4	5	5	95

Dominances	Target components	Reference	Relationships	Conditions	Reasons	Score					Average	Code
						A	B	C	D	E		
	n		ด้านล่างภายในสถานที่ก่อสร้างที่มีแรงงานและพนักงานเดินผ่าน	น้อยกว่า 150 เมตร	เกิดขึ้น							
Site constraints	Passenger lifts	B5	ข้างล่าง Passenger lift ควรจะไม่มีผู้ใดเดินผ่านได้	เมื่อมีการใช้ Passenger lift	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้น	5	5	5	5	5	5	96
Traffic on the site	Concrete pump	B3	ควรใช้ Concrete pump เป็นแบบ Stationary	เมื่อรถบรรทุกสามารถเข้ามาภายในสถานที่ก่อสร้างได้สะดวก	เพื่อสนับสนุนการทำงานให้ได้ Productivity มากขึ้น	5	5	5	5	5	5	97
		B3	ควรใช้ Concrete pump เป็นแบบ Mobile	เมื่อรถบรรทุกไม่สามารถเข้ามาภายในสถานที่ก่อสร้างได้สะดวก	เพื่อให้สามารถทำงานได้	5	5	3	5	5	5	98
		B3	รถควรจะสามารถจอดเพื่อยิงคอนกรีตได้อย่างทั่วถึงรอบอาคาร	เมื่อ Concrete pump เป็นแบบ Mobile และรถบรรทุกปูนสามารถเข้ามาในสถานที่ก่อสร้างได้	เพื่อสนับสนุนการทำงานให้ได้ Productivity มากขึ้น	5	5	4	5	5	5	99
		B3	รถบรรทุกคอนกรีตควรจะสามารถจอดด้านนอกเพื่อยิงคอนกรีตได้อย่างทั่วถึงรอบอาคาร	เมื่อ Concrete pump เป็นแบบ Mobile และรถบรรทุกปูนไม่สามารถเข้ามาในสถานที่ก่อสร้างได้	เพื่อสนับสนุนการทำงานให้ได้ Productivity มากขึ้น	5	1	5	5	5	5	100
Man power	Site office	A1	ขนาดของ Site office พิจารณาจากจำนวนบุคลากรใน Site office นั้น คูณด้วยพื้นที่ของแต่ละคน	เมื่อ Site office เป็นแบบสร้างใหม่		5	5	5	5	5	5	101

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score A	Score B	Score C	Score D	Score E	Average	Code
		A1	ขนาดของ Site office พิจารณาจากขนาดของตู้คอนเทนเนอร์แบบสร้างสำเร็จ (2.5 x 6 ม.)	เมื่อ Site office เป็นแบบสร้างสำเร็จ		5	5	5	5	5	5	102
Duration of the project	Passenger lifts	B5, B18	สำหรับงานที่มีระยะเวลาโครงการสั้น อาจควรจะเพิ่มจำนวนและจุดที่ตั้ง Passenger lift	เมื่อมีระยะเวลาการทำงานน้อยกว่าหรือเท่ากับ 24 เดือน	เพื่อสนับสนุนการทำงานของแรงงานให้ได้ Productivity มากขึ้น	2	5	5	5	2	5	103
Specification and Regulation	Site office	B6	Site office ควรจะเป็นแบบสร้างใหม่	เมื่อมีข้อกำหนดเรื่องขนาดหรือส่วนประกอบต่างๆของ Site office	เพื่อให้สามารถสร้าง Site office ที่ตรงต่อข้อกำหนดได้	5	5	5	5	5	5	104
Specification and Regulation /Man power	Toilet	A7	ควรจะมีการออกแบบจำนวนห้องให้รองรับกับกฎหมาย กฎกระทรวงฉบับที่ ๖๓ (พ.ศ. ๒๕๕๑) ออกตามความในพระราชบัญญัติควบคุมอาคาร พ.ศ. ๒๕๒๒		เพื่อให้การทำงานถูกควรจะตามกฎหมาย	5	5	5	5	5	5	105
Specification and regulation	Tower crane	B1	Tower crane ไม่สามารถหมุนออกไปด้านนอกสถานที่ก่อสร้างได้	ยกเว้น พื้นที่ที่ผ่านไปมีเจ้าของเป็นเจ้าของเดียวกับของสถานที่ก่อสร้างและได้รับอนุญาตแล้ว	เพื่อป้องกันอุบัติเหตุที่อาจเกิดขึ้น	5	5	5	5	4	5	106
Specification and regulation/ Site constraints	Mobile cement plant	B4	ตั้ง Mobile cement plant ที่ด้านหน้าของสถานที่ก่อสร้าง	เมื่อมีการใช้ Mobile cement plant ในสถานที่ก่อสร้างและทาง Supplier	เพื่อลดความวุ่นวายภายในสถานที่ก่อสร้าง	5	5	5	5	5	5	107

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score					Ave rage	Code
						A	B	C	D	E		
				ควรจะการให้ตั้งที่ด้านหน้า								
		B4	ตั้ง Mobile cement plant ที่ด้านหลังของสถานที่ก่อสร้าง	เมื่อมีการใช้ Mobile cement plant ในสถานที่ก่อสร้างและทาง Supplier ไม่ได้กำหนดสถานที่ตั้ง	เพื่อป้องกันฝุ่นให้อยู่ภายในสถานที่ก่อสร้างเท่านั้น	5	5	5	5	5	5	108
Method of work	Steel yard	B12	ขนาด Store เหล็ก ใช้วิธีการเทียบ % ของ Free space ใน Site กับ % ของขนาด Steel Yard เมื่อลำดับสูตรใหม่ จะได้ว่าขนาด Steel yard เท่ากับขนาดโครงการบวกด้วยห้าเท่าของพื้นที่ว่างทั้งหมดส่วนด้วยหนึ่งร้อย	เมื่อใช้หลักการจัดการ Steel Yard แบบสำรองเป็นรอบงาน	เพื่อให้สามารถบริหารจัดการพื้นที่ให้เกิดประโยชน์สูงสุด	5	5	5	5	5	5	109
	Tower crane	B1, B24	ควรมี Tower crane แบบติดตั้งด้านนอกอาคารอย่างน้อย 1 ตัวที่ครอบคลุมบริเวณ ที่มี Tower crane อยู่ภายในอาคาร	เมื่อมีการตั้ง Tower crane ภายในอาคารและมีการใช้ Tower crane ในสถานที่ก่อสร้างมากกว่า 1 ตัว	เพื่อสนับสนุนการเก็บงานที่จะเกิดขึ้นในอนาคตให้ทำได้รวดเร็วไม่ติดขัด	5	5	3	5	5	5	110
		B1, B24	ควรติดตั้ง Tower crane ที่ด้านข้างอาคาร	เมื่อมีการใช้ Tower crane เพียง 1 ตัวในสถานที่ก่อสร้าง	เพื่อสนับสนุนการทำงานในอนาคตที่กำลังจะเกิดขึ้นทำให้เก็บงานได้เร็วและไม่กระทบกับงานส่วนอื่นๆมากนัก	5	5	4	5	4	5	111

Domi-nances	Target compo-nents	Refe-rence	Relation-ships	Condi-tions	Reasons	Score					Average	Code
						A	B	C	D	E		
		B1, B24	ควรติดตั้ง Tower crane 2 ตัว	เมื่อขนาดของอาคารก้ำกึ่งที่จะสามารถใช้ Tower crane ตัวเดียวหรือสองตัว เพื่อให้ครอบคลุมอาคารและพื้นที่กองเก็บวัสดุได้	การใช้งาน Tower crane เพียงตัวเดียว ทำให้เสถียรภาพและความรวดเร็วในการทำงานลดลง ซึ่งไม่คุ้มค่าที่จะเสี่ยง	5	5	4	5	4	5	112
Type of the building	Tower crane	B1	ควรจะมีการใช้ Tower crane	เมื่ออาคารที่ก่อสร้างเป็นอาคารสูง ในเขตเมือง	เพื่อสนับสนุนการทำงานให้ได้ Productivity มากขึ้น	5	5	5	5	5	5	113

Appendix D

All of the final rule bases

Remark: "Ref." means references of the corresponding rule bases from Appendix C.

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
2, 3	DB 01	Design of the building	Tower crane	Should be installed at the wall made from masonry or prefabricated material and have columns to be reinforced as the first priority. If it is possible, the finishing should be prefabricated prior to plastering.	When decide to place tower cranes at the side of the building and have masonry wall or prefabricated wall which has prefabricated finishing.	To reduce the refurnish time and does not obstruct other work.
2, 3	DB 02	Design of the building	Tower crane	Should be installed at the Shear wall which has prefabricated Finishing prior to the plastering finishing. The tower crane can be attached to the shear wall directly.	When decide to place tower cranes at the side of the building and have prefabricated finishing shear walls but do not have masonry walls.	To reduce the refurnish time.
4	DB 03	Design of the building	Tower crane	Should not be installed at the glass.	When decide to place tower cranes at the side of the building.	To prevent the risk of the accident.
5	DB 04	Design of the building	Tower crane	Tower cranes should cover the building and storages over 97%	When the height of the building is less than or equal to 50 metres.	To raise the effectivenes s of the tower cranes. If it is necessary, the mobile tower crane can be used to support the area where the

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
						normal tower crane cannot support.
5	DB 05	Design of the building	Tower crane	Tower cranes should cover all of the building and storages.	When the height of the building is higher than 50 metres	There are no equipment which can support the work except the tower cranes.
6	DB 06	Design of the building	Tower crane	Tower cranes should be placed symmetrically	When the constructing building is symmetric.	To raise the effectiveness of the tower cranes.
34	DB 07	Design of the building	Tower crane	Tower cranes should be placed at the location where the masts of tower cranes can go straight through the building		To facilitate the installation
7	DB 08	Design of the building	Con-crete pump	The distance from the building to the position of the pipe should not exceed 60 metres.	When the stationary concrete pump is used on the site.	To be able to pour the concrete effectively.

Ref.	Cod e	Factor	Target compo- nents	Relationships	Conditions	Reasons
8	DB 09	Design of the building	Con- crete pump	The distance from the building to the location where the Mobile concrete pump can access should not exceed 50 metres.	When the mobile concrete pump is used on the site.	To be able to pour the concrete effectively.
10	DB 10	Design of the building	Con- crete pump	The pipe of the concrete pump can be attached at the side of the building.	When the interested area can let the pipe of the concrete pump to go through straightly.	To reduce the refurnish time, raise the productivity , and be able to pour concrete.
9	DB 11	Design of the building /Method of work	Con- crete pump	The pipe of the Concrete pump can be installed through a Lift core or a Stairs core which can be furnished later than structural work requiring concrete supplying	When the stationary concrete pump is used on the site.	To reduce the refurnish time and does not obstruct other work.
11, 12	DB 12	Design of the building	Con- crete pump	The pipe should be installed at the wall made from masonry or prefabricated material as the first priority. If it is possible, the finishing should be prefabricated prior to plastering.	When decide to use the stationary concrete pump and have masonry wall or prefabricated wall which has prefabricated finishing.	To reduce the refurnish time and does not obstruct other work.
11, 12	DB 13	Design of the building	Con- crete pump	The pipe should be installed at the Shear wall which	When decide to use the stationary	To reduce the refurnish

Ref.	Code	Factor	Target components	Relationships	Conditions	Reasons
				has prefabricated Finishing prior to the plastering finishing. The pipe can be attached to the shear wall directly.	concrete pump and have prefabricated finishing shear walls but do not have masonry walls.	time.
13	DB 14	Design of the building /Method of work	Con-crete pump	The pipe should not be installed at the glass.	When decide to use stationary concrete pump.	To reduce the risk of the accident.
14	DB 15	Design of the building	Con-crete pump	The distance from the concrete pipe going through the building to the concrete pump should not exceed than 30 metres.	เมื่อ Concrete pump เป็นแบบ Stationary	To be able to pour the concrete effectively.
16	DB 16	Design of the building	Passen-ger lifts	Should have passenger lifts at least 2 sets	When the width of the building is wider than the length 2 times or the area per floor exceeds 10,000 sq.m.	To raise the productivity of the labours.
17	DB 17	Design of the building /Man power	Passen-ger lifts	Should have one more Passenger lift	When the work area per floor per passenger lift is higher than 1,000 sq.m. or the number of the labours exceeds each 200 people.	To raise the productivity of the labours.
19, 20	DB 18	Design of the building	Passen-ger lifts	Should be installed at the wall made from masonry or prefabricated material as the	When have masonry wall or prefabricated wall which has prefabricated finishing.	To reduce the refurnish time and does not obstruct

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
				first priority. If it is possible, the finishing should be prefabricated prior to plastering.		other work.
19, 20	DB 19	Design of the building	Passen-ger lifts	Should be installed at the Shear wall which has prefabricated Finishing prior to the plastering finishing.	When have prefabricated finishing shear walls but do not have masonry walls.	To reduce the refurnish time.
21	DB 20	Design of the building	Passen-ger lifts	Should not be installed at the glass.	When decide to place tower cranes at the side of the building.	To reduce the risks of the accident because the passenger lifts have to stay until the last phase of the constructio n. The lubricant might damage the glass.
22	DB 21	Design of the building	Passen-ger lifts	The passenger lifts should be installed not further than 100 metres from the furthest distance of the work space.		To raise the productivity of the labours.
23	DB 22	Design of the building	Passen-ger lifts	Passenger lifts should be placed at the location where the rails of the passenger lifts can go straight through the building.		To facilitate the installing.

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
24	DB 23	Design of the building	Mobile cement plant	The mobile cement plan should be used.	When the amount of concrete is more than 40,000 cu.m.	To raise the effectiveness of the mobile cement plant.
26	CC 01	Compo-nent con-straints/ Design of the building	Tower crane	Tower cranes can be installed into lift cores and stairs cores.		This installation saves the expense from the purchasing of masts and the modification of foundations. However, it reuiqres the assistance from other tower cranes when the tower crane inside the lift core has to be removed which also costs expense. Moreover, it obstructs the lift and stairs construction which the user has to plan the work schedule carefully

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
27	CC 02	Compo-nent con-straints	Tower crane	Tower cranes can be installed at the side of the building.		To reduce the refurnish time but has the price of mast and modification of the foundation in exchange.
28	CC 03	Compo-nent con-straints	Tower crane	Tower cranes can be installed inside the building through the blocking floors		This method might be expensive due to the blocking of the building and modification of the foundation. Consider not
25	CC 04	Compo-nent con-straints/ Design of the building	Tower crane	Tower cranes can be installed on the site without any bracing.	When the height of the building does not exceed 30 metres.	This installation can be only used with the building which is shorter than 30 metres.
29	CC 05	Compo-nent con-straints/ Design of the building	Tower crane	Tower cranes should be installed outside of the building prior to inside of the building.	When the coverage of tower cranes of the final layout does not differ much.	Because installing outside will be able to refurnish the building when the project is going to be finished. Uninstalling the

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
						outside tower cranes is also easier because they do not have to get the assistance from the derrick crane.
30	CC 06	Compo-nent con-straints	Tower crane	Tower cranes should be fixed jib.	When the rotation of the tower crane at that position is better than 80% or at least better than 50%	To maximize the effectivenes s of the usage.
31	CC 07	Compo-nent con-straints	Tower crane	Tower cranes should be luffing jib.	When the rotation of the tower crane at that position is better than 50% or at least better than 20%	To maximize the effectivenes s of the usage.
32	CC 08	Compo-nent con-straints	Tower crane	Tower cranes at every location should be able to rotate not less than 20%.		To maximize the effectivenes s of the usage.
33	CC 09	Compo-nent con-straints	Tower crane	Tower cranes should not be installed further than 6 metres from the constructing building.	When there are tower cranes which are installed at the side of the building.	To let the tower cranes are able to do the work.
35	CC 10	Compo-nent con-straints	Tower crane	Normal sizes of Tower cranes are 30, 35, 40, 45, and 50 metres.	When the capacity of tower cranes can sustain the weight of the	To let the user be able to find the available tower

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
					material.	cranes which go along with the planning.
36	CC 11	Compo-nent con-straints/ Dura-tion of the project	Site office	Use a prefabricated site office.	When the site office has to be moved inside the constructing building and the duration of the project is shorter than 2 years.	
37	CC 12	Compo-nent con-straints	Site office	Use a newly build site office.	When the site offices do not have to be moved inside the constructing building, the duration of the project is longer than 2 years, and the user does not have prefabricated site offices.	
38	CC 13	Compo-nent con-straints	Site office	Can use either newly built or prefabricated site office.	When the user has prefabricated site offices and the duration of the project is longer than 2 years.	
39	CC 14	Compo-nent con-straints	Toilet	Staff’s toilets should be placed separately from labours toilets.	When the site office is prefabricated.	Because labours toilets have strong odor
40	CC 15	Compo-nent con-straints	Toilet	The size of toilets should be between 1.5 to 4 sq.m. per room.		To maximize the worthiness of the land

Ref.	Code	Factor	Target components	Relationships	Conditions	Reasons
						usage.
93	CC 16	Component constraints	Store	The size of the store should be around 65 to 80 sq.m.		To maximize the worthiness of the land usage.
41	CC 17	Component constraints	Concrete pump	A concrete pump is sustainable to do the job.		To maximize the effectivenes s of the usage.
42	CC 18	Component constraints	Concrete pump	The concrete pump should not have more than a bend.	When the concrete pump is stationary.	To prevent the unnecessary loss of the pressure.
15	CC 19	Component constraints	Passenger lifts	There are two types of passenger lifts; Single cage and double cages		To let the user be able to find the available passenger lifts which go along with the planning.
43	CA 01	Component constraints	Passenger lifts	Consider to choose the component which the user has already had.		To save the cost from renting or purchasing.
44	CA 02	Component constraints	Tower crane	Consider to choose the component which the user has already had.		To save the cost from renting or purchasing.
46	CA 03	Component availability	Site office	Consider to choose the material which the user has already had.	When the site office is prefabricated.	To save the cost from renting or purchasing.
47	CA 04	Component	Store	Consider to choose the	When the store is prefabricated.	To save the cost from

Ref.	Cod e	Factor	Target compo- nents	Relationships	Conditions	Reasons
		avai- lability		material which the user has already had.		renting or purchasing.
45	CA 05	Compo- nent avai- lability	Con- crete pump	Consider to choose the component which the user has already had.		To save the cost from renting or purchasing.
49	CR 01	Compo- nents' relation- ship on the site	Mobile cement plant & Site office	The site office should be located at the opposite site of the mobile cement plant	When the mobile cement plant is utilized on the site	To reduce the risk of an accident from the concrete trucks and dust.
50	CR 02	Compo- nents' relation- ship on the site	Site office & Toilet	The staff's toilet should be located inside the site office. The amount of rooms should be at least a room for each gender.	When the site office is newly built.	To support the workflow of the staff because they do not have to walk outside to go to the toilets.
51	CR 03	Compo- nents' relation- ship on the site	Site office & Toilet	Staff's toilet should be located not further than 50 metres from the site office.	When the site office is prefabricated or does not install the toilet inside the newly built site office.	To support the workflow of the staff because they do not have to walk far away to go to the toilets.
52	CR 04	Compo- nents' relation- ship on the site	Passen- ger lifts & Toilet	Toilets should not be located near passenger lifts.		To reduce the risk of an accident.

Ref.	Code	Factor	Target components	Relationships	Conditions	Reasons
53	CR 05	Components' relationship on the site	Tower crane & Steel yard	The steel yard should be located inside the coverage of tower cranes.		Tower cranes can support the work.
54	CR 06	Components' relationship on the site	Tower crane & Laydown area	The laydown area should be located inside the coverage of tower cranes.		To let the tower crane to be able to support the transporting.
55	CR 07	Components' relationship on the site	Tower crane & Toilet	Toilets should not be located inside the coverage of tower cranes.	When toilets can be located outside of the overage of tower cranes.	To reduce the risk of an accident.
57	CR 08	Components' relationship on the site	Entrance gate & Traffic on the site	Specify a gate to be an entrance and another gate to be an exit.	When trucks can drive through between these two entrances and makes the traffic condition on the site clear.	To relieve the traffic condition on the site but should hire more security guards to stay at both entrances.
58	CR 09	Components' relationship on the site	Site office & Store	Store should be located near the site office.	When the store has to keep valuable material.	The security guard can keep protect both component at the same time.
60	CR 10	Components' relationship on the site/ Traffic on the site	Entrance gate & Laydown area	Laydown area should be located close to the entrance gate	When trucks cannot access onto the site.	To raise the productivity of the transportation.

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
15	TB 01	Type of the building	Passen-ger lifts	Should have passenger lifts at least 1 location and 1 unit	When the building is high-rise.	To raise the productivity of the labours.
61, 95	TB 02	Type of the building	Site pro-tection	A safety roof should be constructed over the walk path on the site.	When the building is high-rise.	To reduce the risk of an accident.
62	TB 03	Type of the building	Con-crete pump	A concrete pump should be used.	When the building is high-rise.	To raise the productivity of the concrete pouring.
113	TB 04	Type of the building	Tower crane	A tower crane should be used.	When the building is high-rise.	To raise the productivity on the site.
63	LS 01	Location of the site	Site pro-tection	A safety roof should be constructed at the side where have pedestrians and cars pass.	When there are pedestrians or cars pass next to the site.	To reduce the risk of an accident.
64	LS 02	Location of the site	Lay-down area	Trucks can be parked outside of the site to do the delivery.	When trucks cannot access to the site, can park outside, and tower cranes can assist the delivery.	To be able to transfer the material.
65	LS 03	Location of the site	Lay-down area	Trucks should be parked outside of the site to do the delivery with the approval from the authorities. The plan should be implemented on the weekends and nights to relieve the traffic condition.	When trucks cannot access to the site, cannot park outside, and tower cranes can assist the delivery.	To be able to transfer the material.

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
66	LS 04	Location of the site	Toilet	Toilets should be placed near man holes.	When there are man Holes around the site.	To facilitate the work.
67	LS 05	Location of the site	Mobile cement plant	A mobile cement plant should be used.	When the traffic around the site is in bad condition and does not have any obstruction from other factors.	To eliminate the risk of the traffic jam and cause the concrete pouring to be not effective.
68	LS 06	Location of the site	Mobile cement plant	If there is a neighbourhood around the site, the mobile cement plant should not be utilized.		To prevent the dust going outside of the site.
70	LS 07	Location of the site	Toilet	Labour's toilets should not be located at the side which have pedestrians or neighbours.	When there is a neighbor or pedestrians walk pass that side.	To prevent the odor going outside of the site
71	LS 08	Location of the site	Tower crane	Tower cranes should be operated carefully.	When the neighborhood is a building which is higher than tower cranes.	To reduce the risk of an accident.
1, 71	LS 09	Location of the site	Tower crane	The tower crane should be luffing.	When the tower crane is placed near the housing nearby and have necessity to rotate to that direction and the fixed jib can cause risk to the neighbourhood nearby.	To reduce the risk of an accident and be able to do the work.

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
78	FS 01	Free space	Steel yard	The steel yard should not exceed 1,600 sq.m.	When the free space is larger than 1,600 sq.m.	To maximize the worthiness of the land usage.
78	FS 02	Free space	Steel yard	The planner should order the steel to stock at the steel yard only to sustain the work cycle.		To maximize the worthiness of the land usage.
109	FS 03	Free space/ Method of work	Steel yard	The size of the steel yard should be equal to the site area plus by the five times of the free space. Then, divide that number with the 100. If the answer is less than 100, consider to fabricate from the outside.		To maximize the worthiness of the land usage.
80	FS 04	Free space	Mobile cement plant	The free space should be at least 1,600 sq.m. left in order to use the mobile cement plant.		To maximize the worthiness of the land usage.
81	FS 05	Free space	Toilet	Toilets should be located at the place where the visitor cannot see clearly.	When there are niches or corners.	To form a good vision for the visitor.
83	FS 06	Free space/ Method of work	Store	The store should be moved into the constructing building.	When the free space is lower than 2,000 sq.m. or 25% of the site.	To maximize the worthiness of the land usage.

Ref.	Code	Factor	Target components	Relationships	Conditions	Reasons
84	FS 07	Free space/ Method of work	Site office	The site office should be moved into the constructing building.	When the free space is lower than 2,000 sq.m. or 25% of the site.	To maximize the worthiness of the land usage.
85	FS 08	Free space	Site office	The site office and the store can be combined to form a 2-floor component.	When the free space is lower than 2,000 sq.m. or 25% of the site and the planner does not want to move the components inside.	To maximize the worthiness of the land usage.
86	FS 09	Free space	Con-crete pump	There should be at least 6x6 m. or 3x12 m. for the parking of trucks (2 trucks).		To raise the productivity of the labours.
88	SC 01	Site con-straints	Lay-down area	The size of the laydown should be equal to 1% of the site area plus with 115 sq.m. but not exceed 300 sq.m.		To maximize the profit from the space using on the site.
89	SC 02	Site con-straints	Site office	The site office should not be located under the material path.	When the material path is a route which the material moved pass. The line can be drawn from the storage to the building.	To reduce the risk of an accident.
90	SC 03	Site con-straints	Site office	The site office should be located at the front of the site.	When there are no mobile cement plants on th site.	To reduce the risk of an accident and facilitate the visitor.

Ref.	Cod e	Factor	Target compo-nents	Relationships	Conditions	Reasons
91	SC 04	Site con-straints	Site office	The site office should be located at the place where can be furnished in the last phase such as garden, and grass field.	When the site office does not have to be moved inside the constructing building.	To reduce the moving cost and does not obstruct other work.
92	SC 05	Site con-straints	Toilet	Toilets should not be located under the material path.	When the material path is a route which the material moved pass. The line can be drawn from the storage to the building.	To reduce the risk of an accident.
94	SC 06	Site con-straints	En-trance gate	Use the same entrance of the finished building as the site entrance unless there are some obstructions. Request new entrance from the authorities costs expenses.		To safe the cost and time that have to be spent with the authorities.
57	SC 07	Site con-straints	En-trance gate	Close the site entrance until there is only an entrance left.	If there are more than 1 entrance gates and there are no connections between these gates.	To raise the safety on the site
96	SC 08	Site con-straints	Passen-ger lifts	The area under the passenger lift should not be accessible.	When the passenger lift is used.	To reduce the risk of an accident.
97	TS 01	Traffic on the site	Con-crete pump	The concrete pump should be stationary	When the concrete trucks can access to the site conveniently.	To raise the productivity of the labours.

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
98	TS 02	Traffic on the site	Con-crete pump	The concrete pump should be mobile.	When the stationary concrete pump cannot be placed on the site or the concrete trucks cannot access to the site.	To be able to pour concrete.
99	TS 03	Traffic on the site	Con-crete pump	The mobile concrete pump should be able to park and shoot concrete to the building sufficiently.	When the concrete pump is mobile but the concrete trucks can access the site.	To raise the productivity of the labours.
100	TS 04	Traffic on the site	Con-crete pump	The mobile concrete pump can shoot concrete from outside of the site.	When the concrete pump is mobile but the concrete turcks cannot access the site.	To raise the productivity of the labours.
77	TS 05	Traffic on the site	Con-crete pump	Concrete trucks should be accessible to the concrete pump.	When the concrete pump is stationary	To raise the productivity of the labours.
73	TS 06	Traffic on the site	Steel yard	Trucks should be accessible to the steel yard	When the trucks can access the site. However, if they cannot, tower cranes can assist the delivery.	To facilitate the steel delivery.
74	TS 07	Traffic on the site	Lay-down area	Trucks should be accessible to the laydown area.	When the trucks can access the site. However, if they cannot, tower cranes can assist the delivery.	To raise the productivity of the delivery.
75	TS 08	Traffic on the site	Mobile cement plant	Trucks should be accessible to the mobile cement plant.		To be able to pour concrete.

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
76	TS 09	Traffic on the site	Store	Pick-up trucks should be able to access the store (The road should be around 2 m.)	When the pick-up trucks can access the site. However if they cannot, labours can assist the delivery.	To facilitate the delivery.
101	MP 01	Man power/ Duration of the project	Site office	The size of the site office can be calculated from the area per person times with the number of persons. The PMs should have at least 4 to 9 sq.m., while, normal staff can have 2 to 5 sq.m. per staff.	When the site office is newly built, the duration of the project is longer than 24 months, and the owner has the specification about the size of the site office.	
102	MP 02	Man power/ Duration of the project	Site office	The size of the site office can be calculated from the area per person times with the number of persons. The PMs should have at least 4 to 9 sq.m., while, normal staff can have 2 to 5 sq.m. per staff. Then, adjust the size to go along with the size of the prefabricated material.	When the site office is prefabricated, the duration of the project is shorter than 24 months, and the owner does not have the specification about the size of the site office.	
103	DP 01	Duration of the project	Tower crane	Consider to place more tower cranes to respond to the tight schedule.	When the duration of the project is less than or equal to 24 months	To raise the productivity of the labours.
103	DP 02	Duration of the project	Concrete pump	Consider to place more concrete pumps to respond	When the duration of the project is less	To raise the productivity of the

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
				to the tight schedule.	than or equal to 24 months	labours.
103	DP 03	Duration of the project	Passenger lifts	Consider to place more passenger lifts to respond to the tight schedule.	When the duration of the project is less than or equal to 24 months	To raise the productivity of the labours.
104	SR 01	Speci-fication and Regu-lation	Site office	The site office should be newly built.	When there is a specification about the size of the site office.	To follow the specification.
105	SR 02	Speci-fication and Regu-lation/ Man power	Toilet	The number of the room has to follow the regulation of the building act. 2 rooms for the number of labour less than 15 people. 4 rooms for the number of labour less than 16-40 people. 6 rooms for the number of labour less than 41-80 people. Finally, extra 2 rooms for each 50 labours.		To follow the regulation.
106	SR 03	Speci-fication and Regu-lation	Tower crane	Tower cranes cannot rotate out of the site.	When the owner of the land nearby does not allow.	To reduce the risk of an accident and legal issue.
49, 107, 108	SR 04	Speci-fication and Regu-lation /Site con-straints	Mobile cement plant	The mobile cement plant should be located at the specific place on the site from the supplier.	When the mobile cement plant is considered to be used and the supplier specifies about the location.	To be able to have the mobile cement plant on the site.

Ref.	Code	Factor	Target components	Relationships	Conditions	Reasons
69, 107, 108	SR 05	Specification and Regulation /Site constraints	Mobile cement plant	The mobile cement plant should be located at the back of the site.	When the mobile cement plant is considered to be used and the supplier does not specify about the location on the site.	To prevent the dust from going outside of the site.
107, 108	SR 06	Specification and Regulation	Mobile cement plant	The location of the mobile cement plant should be approved from the owner first.	When the mobile cement plant is considered to be used.	To be able to have the mobile cement plant on the site.
109	SR 07	Specification and Regulation	Mobile cement plant	The usage of the mobile cement plant should be approved by the supplier first.	When the mobile cement plant is considered to be used.	To be able to have the mobile cement plant on the site.
107, 108	SR 08	Specification and Regulation	Site protection	The constructing tower should be covered by the mesh sheet to prevent dust.	When there is a regulation about dust on the site.	To prevent the dust from going outside of the site.
110	MW 01	Method of work	Tower crane	Should have at least one tower crane installed at the side of the building if there is at least one tower crane inside the constructing building.	When there are more than a tower crane on the site and have at least a tower crane inside the constructing building.	To support the refurnish work on the site in the future.
111	MW 02	Method of work	Tower crane	Consider to install the tower crane at the side of the building.	When there is only a tower crane used on the site.	To support the refurnish work on the site in the future so that the building

Ref.	Code	Factor	Target compo-nents	Relationships	Conditions	Reasons
						will not have to be heavily refurnished.
6, 103, 112	MW03	Method of work	Tower crane	Be able to place more tower cranes than the system proposes	When the redecoration time of the wall is longer than 1 month	Having tower cranes at 2 or more places can raise the stability and productivity of the site.
103, 112	MW04	Method of work	Passen-ger lifts	Be able to place more passenger lifts than the system proposes	When the redecoration time of the wall is longer than 1 month	Having passenger lifts at 2 or more places can raise the stability and productivity of the site.
23	MW05	Method of work	Passen-ger lifts	The passenger lift should start the operation at the second floor.	When the passenger lift does not have to assist the delivery.	To relieve the crowd on the first floor.
82, 93	MW06	Method of work	Store	Consider to use the prefabricated store with the size of approximately 65-80 sq.m. The precise size should be concerned from the size of the available material (usually 2x6 m.).	When the store has to be moved inside the building.	If the user chooses peculiar size, he might not be able to find the material.

VITA

Natthapol Saovana was born on November 13th, 1989 in Bangkok, Thailand. He studied at Bangkok Christian College since grade one to grade twelve. He extended his education profile in the Department of Civil Engineering, the Faculty of Engineering, Chulalongkorn University for his Bachelor’s degree. He graduated his Bachelor’s degree in 2012. He continued studying for his Master’s Degree in the Division of Construction Engineering and Management and graduated in 2015. He works in a construction company as an estimator and a researcher to expand his experience in the field, while requesting a scholarship for the Doctor’s degree.