Case study on the applicability of a construction site layout planning system

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Abstract

This study presents the development and application of a construction site layout planning (CSLP) system, emphasizing the importance of efficient, safe, and cost-effective planning in construction management. Recognizing the limitations of current algorithmic and simulation-based approaches, this research advocates for a CSLP system that prioritizes communication speed, ease of use, and adaptability over precision, integrating user experience and intuition into the planning process. A prototype CSLP system is developed based on these principles. It incorporates actual business process and decision support functionalities to address the dynamic nature of construction sites, supporting user-dependent planning. The system's development was informed by a comprehensive literature review that identifies gaps in existing CSLP tools and methodologies, leading to a new framework that aligns with practical field requirements. The effectiveness of the prototype is evaluated through a case study on an apartment complex construction site. This study assesses the system's capacity to deliver appropriate planning information and support plan review. The methodology includes a thorough analysis of the CSLP creation process, prototype development based on identified functional requirements, and a case study for validation. Findings indicate that the prototype enhances decision-making, improves safety, and optimizes the placement of temporary facilities. It facilitates collaboration and information sharing, thereby improving overall project management. This research contributes to construction project management theory by proposing a user-centred CSLP system that significantly improves efficiency, safety, and cost-effectiveness in construction projects.

Keywords –

Site layout; Temporary facilities; Plan assessment; Case study

1 Introduction

In the field of construction management, CSLP is an important consideration from the very beginning of a project, determining the size, number, and type of temporary facilities required for the project [1]. These facilities must be located within the project site appropriately and can include offices, guardhouses, restrooms, yards, workshops, shifts, water pumps, tower cranes, etc. [2]. The placement of temporary facilities has a significant impact on the cost, time, and safety of a project, and, thus, is critical for efficient project operations [3].

Many researchers have recognized the importance of CSLP and have conducted research on mathematical calculations and genetic algorithms for equipment and personnel movement, facility location optimization, safety, and transportation costs [4]–[7]. However, because CSLP is created in the early stages of a project, there is a high degree of variability in the plan, and the placement precision required in the field is lower for temporary facilities than for construction objects. Therefore, CSLP tools for the field should focus on communication speed and ease of use rather than placement precision. Algorithmic and simulation methods for identifying the best locations for temporary facilities often fall short in real-world applications. This is primarily due to their reliance on predetermined sizes and quantities, which may not align with practical situations. This misalignment hinders practitioners from implementing these approaches. To overcome these limitations, CSLP tools need to be integrated with business processes where users utilize them as decision support tools, and where human interaction with the tools leads to CSLP results. Therefore, in CSLP system development, it is important to determine how decision support functions can be effectively combined with existing CSLP creation processes through user experience. In addition, user experience and intuition are important factors in deployment planning decisions, as they allow users to periodically update the required information in the plan to reflect changes in the field situation and improve decision-making by better understanding on the available resources (i.e., personnel, materials, and equipment). Therefore, the CSLP system should have a user-dependent structure.

In addition, the main purpose of a temporary facility layout plan in a construction project is to outline the route and potential hazard spaces before construction begins. Typically, this risk assessment is done in accordance with the legislation applicable to the construction phase and the company's manual. However, this review process is highly dependent on the subjective judgment of the planner. Therefore, there is a need for an auxiliary information provision function that enables more effective judgment of rough movements and potential hazard spaces.

In this study, a prototype of a CSLP system is developed, and a case study is conducted to evaluate how well the system meets the requirements. We develop a prototype of a CSLP system and reenact the CSLP process through a case study. In doing so, we examine the following two main aspects: 1) whether the CSLP output effectively conveys the appropriate level of planning information, and 2) whether the additional information provided is useful for plan review.

2 Method

The methodology of this study consists of three parts.

Analysis of the CSLP creation process: We thoroughly analysed each process required to create a CSLP. Through this analysis, we derived the functional requirements for each procedure, which is the basis for system development.

Prototype development: We developed a CSLP prototype system based on the functional requirements obtained by referring to previous studies. This prototype was designed to reflect the functional requirements.

Validation through case study: We conducted a case study to validate the effectiveness of the developed prototype. This process evaluated whether the CSLP prototype meets the functional requirements defined earlier. The feedback from the case study would play an important role in the further improvement of the prototype.

3 Literature Review

In a different direction from algorithmic research, there is research on developing tools to support material and equipment location planning to address safety, cost, and time issues on construction sites [8]–[12](Table 1).

In [8], a computerized system (ArcSite) for CSLP was developed. The system integrates a GIS and a DBMS to automatically identify and place the best locations for temporary facilities. In [9], a genetic algorithm-based model (EvoSite) was developed to optimize CSLP. The main difference between the two early systems is the environment in which the site and temporary facilities are modelled. ArcSite is designed for layout planning modelling in GIS, i.e., continuous space environment, and EvoSite is designed for layout planning and result presentation in grid system environment, which is easy to apply genetic algorithm.

To address the complexity and uncertainty of CSLP, [10] proposed a simulation-based decision support tool (DST), which also uses rectangular facility modelling and Euclidean distance function for optimization of equipment, material, and worker placement in a grid system environment. Modelling in digital environments tends to focus on drawing methods in continuous space environments and prefer grid environments for optimization and plan review.

In [11], a new automation framework integrating BIM and optimization algorithms for prefabricated building CSLP is proposed. Recently, there have been attempts to combine BIM and parametric modelling support tools (e.g., Dynamo) into CSLP. However, these methods differ significantly from current practice and are limited in terms of user accessibility.

The work of [12] provides some insight into the functional requirements of a CSLP tool. In this study, several parameters essential for CSLP were extracted through social network analysis. These parameters are classified into four main categories, and in particular, three parameters (i.e., modelling a continuous site space, considering the site's surrounding environment, main and secondary traffic roads for project gates) belonging to the construction site category are used in this study to set the development direction of the CSLP system.

The CSLP support tools presented in the aforementioned studies have the disadvantage that they do not sufficiently consider integration with existing CSLP creation processes. This leads to a decrease in the accessibility of users to new tools for CSLP creation, so the system development was organized by simulating the work processes of 1) site surrounding investigation, 2) layout drawing, 3) layout evaluation and review, and 4) modification and maintenance.

In addition, the collaboration function facilitates the flow of information, helping all relevant parties to get the information they need in a timely manner. This contributes to the improved quality of decision making and reduced misunderstandings between them [13]. For proper CSLP consensus, the collaboration functions of the system are crucial. For this purpose, we have integrated a documentation task generation function into the system to help support information sharing and communication.

Table 1 Existing CSLP systems & tools

Reference	Research purpose	Approach	Utilized elements
[8]	Optimization of temporary facility layout in Construction site	Development of GIS and DBMS integrated system(Arcsite), use of heuristic algorithms and proximity index	Drawing method over continuous space environment
[9]	Development of an optimization model for CSLP	Development of the genetic algorithm-based Evosite system	Use of grid system for applying analysis algorithm
[10]	Development of a simulation-based decision support tool for construction site layout planning	Development of a simulation-based decision support tool (DST)	Use of grid system for applying analysis algorithm
[11]	Automation of layout planning for prefabricated construction sites	Integration of BIM and optimization algorithms, use of GA and PSO	Exclusion of parametric modelling support tools for user accessibility
[12]	Analysis and identification of research gaps in construction site layout planning models	Analysis of existing research models using social network analysis (SNA)	Utilization of parameters for CSLP tasks

4 Description of CLSP process incorporated in proposed System

The functions of the system were derived by considering the functions and information required by users to perform CSLP tasks, as described in [14]. The functions of the CSLP system are categorized based on the order in which the CSLP was created in practice and are defined as 1) Surrounding Situation Investigation, 2) Drawing Site layout Planning, 3) Layout Evaluation and Review, and 4) Modification and Maintenance. The reason for categorizing the functions according to the order of creation is to make it easier for potential system users to accept and quickly adapt to the new system in a similar way to the existing CSLP creation method.

The functions are placed in the order of the existing CSLP creation, as shown in Figure 1, and this order defines the modules from which they will be recruited in the system.

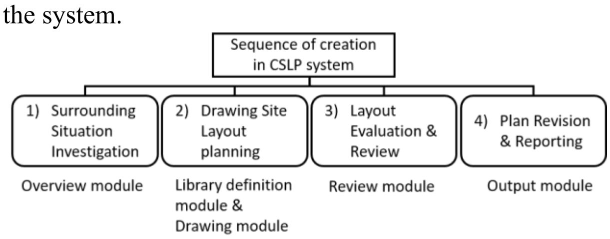

Figure 1. Hierarchy of CSLP system functions and system modules.

4.1 Functional Requirements for CSLP System Module

This section describes the CSLP authoring process and the authoring order considered. It identifies the modules defined in the creation order and the functional requirements considered in each module. This is presented in Figure 1.

1) *Surrounding Situation Investigation*: The user needs to investigate the surrounding environment of the site where the project will be started. In this step, the surrounding factors, such as terrain, transportation accessibility, and neighbouring buildings, are checked, and information is collected. For example, by considering the presence or absence of major roads or residential complexes, the user can prevent complaints that may arise after the project starts and plan solutions to resolve them. Reporting on the surrounding conditions is also an important part of the existing CSLP planning report.
2) *Drawing Site Layout Planning*: The user designs the layout of the construction site based on the collected surrounding information. In this process, the space arrangement is established by considering buildings, equipment, materials, security, etc. The user considers the number, size, and type of temporary facilities required for the project and determines the location of the required facilities.
3) *Layout Evaluation and Review*: This is the stage of reviewing and evaluating the designed layout, considering the efficiency, safety, environmental impact, and schedule of the construction process. The CSLP is evaluated and revised if there are any inadequacies. It is also important to consider site management, material management, worker transportation, and safety.
4) *Plan Revision and Reporting*: In this step, the maintenance and management plan is developed,

and the plan is verified and adjusted. The user shares the plan with stakeholders and incorporates their feedback. Generating the reports on temporary facility deployment would increase work efficiency and facilitate information sharing with stakeholders. Information is delivered in the form of data files, which facilitates the exchange of views between the user and stakeholders.

As a result, the eight functional requirements (i.e., R1 to R8) considered in the system are described below.

- (R1) The system needs to be integrated with imagery that shows geographical characteristics so that users can understand their surroundings.
- (R2) The system should be able to help the user plan the CSL (construction site layout) without missing any temporary facilities that need to be placed.
- (R3) When starting a construction project, the system should be able to utilize the CAD files that are naturally available and reflect the accuracy of the site location and scale in the CSLP.
- (R4) The system should allow the user to have visibility into the planned CSL and identify hazardous areas.
- (R5) It should confirm that the paths between equipment and workers do not overlap for the safety of workers on site.
- (R6) It should allow for schedule conscious CSL, as schedules may require unnecessary temporary facilities to be moved or removed.
- (R7) The user should be able to derive the planned CSL in a report format to reduce the time spent on paperwork.
- (R8) The user should be able to generate data in flexible file formats that support communication with stakeholders, which are time- and location-independent.

4.2 Development of the interface design

In the development of the User Interface (UI) for a CSLP system, our strategy was firmly rooted in fostering an intuitive and efficient interaction between the user and the system. By diligently applying the four UI design principles established by [15], we anticipated a significant enhancement in the user experience, particularly in terms of communication with potential users.

- Familiarity: We adopted the ribbon interface framework, widely recognized from Microsoft applications, to minimize the learning curve and ensure a consistent user experience across platforms. This decision promotes intuitive engagement with the application by leveraging familiar elements.
- Clarity: We emphasized clarity in our design for visual presentation, conceptualization, and terminology. Specifically, in the design of function icons, we aimed to reduce user errors and increase efficiency, making the application more intuitive and accessible.
- Grouping: We organized function modules logically to make it easier for users to quickly find and understand the information they need. This approach supports cognitive ease, aiding users in categorizing and recalling application functionalities, thus optimizing navigation and usability.
- Compatibility: We ensured our UI supports compatibility with multiple software file formats to accommodate the varied task and job requirements of our users. This is crucial for CSLP activities, allowing seamless integration of a wide array of file formats into their workflows, thereby broadening the application's applicability and flexibility.

5 CSLP System Application through a Case Study

To verify that the proposed CSLP meets the requirements, a case study was conducted in an apartment complex site. The existing temporary facility layout plan, CAD drawings, and project schedule information are utilized to derive the CSLP using the prototype system. The case study follows the sequence of system modules shown in Figure 1 in Chapter 4, which allows to evaluate the functional completeness of the aforementioned requirements.

The case study is based on an apartment site located in a city centre in Korea, and the construction work was carried out over a period of 28 months from September 2015 to January 2018. The site consists of five apartment buildings and is surrounded by a residential complex with a shopping centre, a school, and a subway station. In preparation for the case study, the data was reformatted for web use by converting the previously received DWG (CAD) files to DXF file format. During the case study, the type, location, and number of temporary facilities are determined by referring to the existing layout plan.

5.1 Overview Module

After accessing the CSLP system, a user can use the project creation function. In the project creation window, the user can search for the address of the apartment construction site, load a map image, and set the start and end dates of the project (Figure 2).

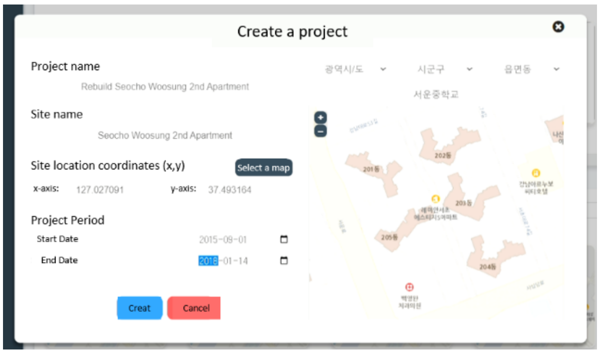

Figure 2. Overview module: Creating a project.

Through this map, the user can identify the surrounding area of the site and consider complaints from neighbouring residential complexes and traffic congestion on the main road (R1). After that, the user can add the prepared project schedule in the project schedule management window (Figure 3).

Figure 3. Overview module: Adding a schedule.

5.2 Library Definition Module

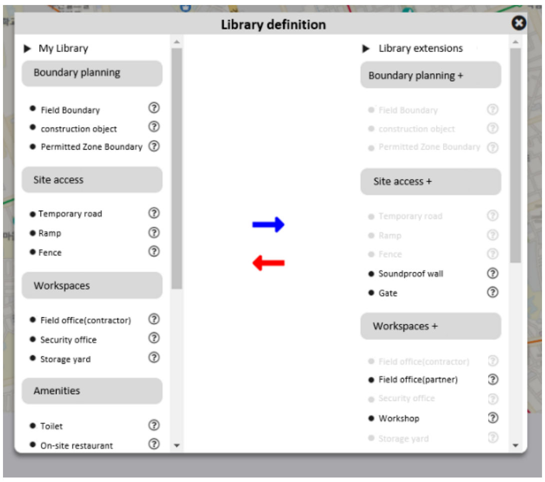

Figure 4. Library Definition module.

In this module, the user specifies the temporary facilities required for the case project. If the user use the “Library Extension” to add the some facilities to “My Library,” the added facilities are displayed on the left side of the system and can be viewed in the Drawing Module. The user can add, delete, and modify facilities to customize them for the case project. This module can be utilized as a checklist of facilities needed in the field (R2) (Figure 4).

5.3 Drawing Module

Before moving to the Drawing module of the system, the user should prepare the site map in the overview step and the list of temporary facilities for his or her project in the library definition step. The user can then load the CAD (DXF) file of the site into the system and place it on the map (① in Figure 5), and refer to the Library on the left to draw various temporary facilities on the map (R3). In this case project, there were 5 apartment buildings, 3 ramps, 4 site offices, 1 restroom, 13 lifts, and 3 T/Cs. Except for the apartments, the rest of the facilities were drawn using shapes (② in Figure 5), and the placement of apartment buildings utilized CAD files to improve the accuracy of the building geometry and enhance visual understanding. In the drawing stage, polygons and dots are placed on the map and coloured to distinguish between facility types intuitively. In this stage, opinions are shared with many stakeholders, and a note function is included to support this (③ in Figure 5). In addition, to allow multiple stakeholders to participate in the project, in this system, the edit mode and view mode are separated for quick plan checking (④ in Figure 5). In addition, the user can capture the screen as he or she creates the CSLP to keep track of the work.

Figure 5. Drawing module.

5.4 Review Module

In this case study, the efficiency and safety of the designed CSLP were evaluated and reviewed. This module includes the ability to identify blind spots and hazardous areas. For example, the Figure 6 is an image of the blind spot identification function, which indicates low visibility locations sequentially from green to yellow to red. In this case, the field shows that the area at the edge of the field has a low visibility score and the centre has a high score. The Figure 7 shows a feature that shows the hazardous areas between temporary facilities and the target building in order from green to yellow to red. This feature shows the danger around lifts, T/Cs, and ramps in red. The results of the hazardous space check are based on the results of the blind spot check, and facilities located in blind spots are displayed as more dangerous (R4). In addition, the "Placement Constraint Check" function allows the user to define maximum separation values for different facilities to check whether overlaps between facilities occur (R5). This feature can be used to select routes that consider the safety of workers. These features help the user evaluate the appropriateness of your CSLP and consider modifications if necessary. In addition, temporary facilities can be scheduled according to the fluid CSLP situation on site, and the system displays the temporary facilities at a specific point in time (R6). In the Review module, the "View Modification Log" function is provided to allow the user to see who modified what, when, and by whom, increasing the transparency of planning and collaboration. The existing CSLP method relies on the individual's ability to review, but the system proposed in this study improves the review function by applying computational algorithms (Figures 6 and 7).

Figure 6. Review module: Checking blind spot.

Figure 7. Review module: Checking hazardous space.

5.5 Output Module

After the CSL is created in the Drawing module and reviewed and adjusted in the Review module, the Output module generates and outputs a CSLP report for the field use (R7). The report includes some details, such as the overall layout plan, redundancy plan, amenities, and workspace, and provides additionally results for hazardous spaces and blind spots identified through the Review module. On the report generation page, the user can make additions or notes, and organize and modify the list of deployed facilities using legends. For example, Figure 8 shows a report of a site access plan, with objects in that category highlighted in the image and labelled in the legend. This report is useful for reducing the amount of additional paperwork required after using the system. At the Output module stage, the user can save a DXF file of the CSLP and a PDF file of the report, which is a convenient file format to deliver to various stakeholders (R8).

Figure 8 Output Module

6 Conclusion

Previous studies on CSLP have pointed out the lack of integration with existing work processes, which leads to the problem of limited user accessibility of CSLP tools. Therefore, a new system developed in this study organizes functions by simulating work processes including site perimeter survey, layout drawing, layout evaluation and review, and modification and maintenance. The system is implemented according to the order of CSLP creation and provides analysis-based information that the existing method does not provide. In the study, a total of eight functional requirements were derived by analysing the four-step CSLP creation process, and the system was developed based on them. Through case studies of selected projects, it was confirmed that these eight requirements were satisfied.

The CSLP system enables efficient and systematic deployment planning compared to the traditional CSLP creation methods, which are typically time-consuming and limited to simple drawing functions. Through algorithmic evaluation, the system overcomes many of the drawbacks of traditional methods, especially time-consuming, the possibility of creating improper batches, and limitations in terms of safety and efficiency. By evaluating user-created CSLPs, the CSLP system helps users review their plans more carefully and determine the optimal placement. It shows significant performance improvements, especially in terms of speed and ease of use. In addition, the system provides the flexibility to incorporate feedback from various stakeholders in real time, which improves the user experience.

This study contributes to construction project management theory through the development of a user-centred construction site layout planning (CSLP) system. If this system is used by construction managers, it will help them to layout and manage temporary facilities more efficiently and precisely, contribute to the improved safety and cost-effectiveness of construction projects.

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