

Construction Site Layout Planning: A Social Network Analysis

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Abstract: Construction site layout planning (CSLP) is the strategic arrangement and planning of construction site spaces, which has an enormous impact on the success of any construction project. Over the past two decades, multiple planning models have been developed to generate layouts that maintain safety and productivity within the construction environment. Yet these models vary significantly with disparate assumptions, many of which remain unstated. This study harnesses social network analysis (SNA) as a means to convert data into knowledge. It applies SNA to shed light on CSLP, providing a comprehensive overview of the existing models, and illuminating the critical parameters that should be considered in layout planning. This analysis delves deep into past methodologies and sets the potential for forthcoming research investigations. This study aims to be a reference for readers and researchers venturing into the realm of CSLP. Numerous related records and studies from diverse databases and sources were reviewed and analyzed. Out of these, 70 articles were singled out, from which 14 pivotal parameters were distilled as the foundation for any CSLP framework. Through the application of SNA, gaps within the existing research domain and literature were pinpointed. The study findings demonstrate the growing interest in shifting to cutting-edge approaches in CSLP. However, the results show that the majority of these models in the literature fall short of sufficiently addressing realistic facility representation, noise effects, or the construction impact on the surrounding environment. Accordingly, this research illuminates these knowledge gaps. The findings of this review guide future research by sketching a broad outline for future optimization models and planning studies.

Keywords: layout planning; social network analysis; systematic literature review; construction sites; layout optimization



Citation: Salah, M.; Khallaf, R.; Elbeltagi, E.; Wefki, H. Construction Site Layout Planning: A Social Network Analysis. *Buildings* **2023**, *13*, 2637. <https://doi.org/10.3390/buildings13102637>

Academic Editor: Bo-Tao Huang

Received: 9 September 2023

Revised: 5 October 2023

Accepted: 11 October 2023

Published: 19 October 2023



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1. Introduction

Construction site layout planning (CSLP) is a vital initial step in any project. It aims to identify the optimal locations of all required temporary facilities (TFs) to enhance construction efficiency and optimize the location of construction resources and processes [1]. A well-organized site layout leads to cost and time savings while also improving safety standards in construction projects [2]. Planning a construction site is not straightforward due to the unique constraints inherent to each project. Previous layout planning models encompass a broad spectrum of underlying assumptions that vary in the problem's definition and the solving methodology.

Numerous publications have undertaken CSLP reviews, yet many have either been case/area-specific or outdated. For instance, Sadeghpour and Andayesh [3] presented an overview of the critical variables and components for site layout modeling, referred to as constructs. Xu et al. [4] shed light on optimization algorithms in CSLP, resolving the problem of selecting a suitable algorithm and improving optimization algorithm utilization.

Ardila and Francis [5] focused on spatiotemporal planning to categorize the research efforts and developments in this domain with their influences on the construction industry. Al-Hawarneh et al. [6] tracked the evolution of optimization algorithms in static and dynamic layout problems. Tariq et al. [7] reported on the trends in crane layout planning over the years. Zolfagharian and Irizarry [8] reported on trends in CSLP, 4D simulation, and a rule-based checking system for site planning. Kim et al. [9] proposed an automated CSLP model for temporary facility constraints.

Social network analysis (SNA) has increasingly been utilized as an effective tool to understand complex dynamics [10–12]. It has been employed to gain deeper insights into business failure factors within the construction sector [10], where it is used to convert data into knowledge and to report on patterns in a specific topic. SNA provides a clearer understanding of various interrelationships or dependencies that might lead to business vulnerabilities [11]. Likewise, this study employs SNA to unravel the numerous elements that may impact collaboration or planning in construction endeavors, highlighting some essential nodes and links crucial for successful collaboration [10].

This study aims to provide a broad and holistic examination of CSLP. The authors intend to draw a predefined path for aspiring researchers in the field by providing a general outline of the key variables, approaches, and optimization objectives in the literature while highlighting potential directions for future research. The authors aim to delineate essential concepts that should be integral to any CSLP model, encompassing available optimization algorithms, previously examined objectives, and gaps in the literature. Additionally, they strive to identify critical parameters influencing the efficacy of planning models. These parameters are analyzed based on their prominence (representation in the literature) with the ultimate goal of proposing a distinctive research framework informed by the study's insights. Hence, this study analyzes the CSLP body of knowledge to pinpoint the key requirements and parameters for site layout planning drawing from an extensive range of prior publications. The conclusions drawn from this analysis can offer a reliable foundation for future researchers to further refine and expand upon existing CSLP models.

2. Background

2.1. Social Network Analysis

SNA is considered a powerful tool that is applied to explore the relationship structures within a network using graph theory concepts (nodes and edges) [13]. It can provide researchers with deeper insights into a specified topic [10]. SNA converts data into knowledge and reports on patterns in a specific topic, with a clearer understanding of various interrelationships or dependencies that might lead to business vulnerabilities [11]. SNA can be applied to analyze key components and critical parameters using metrics, as it quantifies the degree of centrality (*DC*) for each reference according to the number of citations in other articles to find the most influential publications in that body of knowledge [11]. *DC* compares the different nodes and shows which ones have more links [10].

Within the construction industry, many authors have employed SNA to delve into critical aspects of the construction industry [10]. Assaad and El-Adaway [10] explored in their work 20 crucial factors and causes of construction business failure, aiming to create a comprehensive framework for business failure prediction. They applied SNA to measure the co-occurrence and frequency of the identified factors to indicate the most influential and overlooked factors, applying centrality measures while comparing the literature (review articles with case studies). Elsayegh and El-Adaway [11] conducted an in-depth review of collaborative planning over the past three decades, while shedding light on 50 factors influencing collaborative effectiveness extracted from past research. Their work aimed to lay a foundation for improved collaborative planning practices in construction projects. They applied SNA to quantify the importance of each indicated factor according to its centrality degree within the factors' network. Eissa et al. [12] mapped out the pivotal role of game theory in the construction engineering and management (CEM) domain, aiming to point out its understanding and applications. They analyzed the evolution of game theory

techniques in the literature to indicate the most influential knowledge areas, topics, and outcomes. Collectively, these studies underscore the potential of SNA and its applications in enhancing various facets of the construction field.

2.2. Construction Site Layout Planning

Site layout planning is a fundamental process for any successful project as it enhances the overall operation's safety, productivity, and security. The construction site space is an environment where all project resources (labor, equipment, and facilities) can work together to execute the assigned activities. Proper identification of the layout plan would increase safety and productivity and enhance on-site maneuverability. Therefore, an optimum allocation of site facilities is essential for an efficient work environment. Most former research studies have aspired to develop an optimum arrangement of temporary facilities (TFs) through the site space with the minimum total cost and maximum safety. In previous literature, the models have had a varied research scope in each of the published articles. Some of the previous studies searched site spaces for the best TF locations [14–16], while others tested the most suitable optimization approach or algorithm by comparing the algorithmic efficiency [16,17]. Multiple studies [13,18–21] identified facility types and sizes as user inputs depending on the project type and the applied construction method. Other researchers (e.g., [15,22–25]) built an optimization algorithm to optimize the required facility sizes for each construction activity.

Construction projects require several facilities to support various activities during the project duration. CSLP is the process of allocating site facilities at optimum locations to build the best arrangement in the site space. Therefore, identifying the activities' requirements for TFs with their service time is critical. According to Ning et al. [26], TFs could be classified as fixed or non-fixed facilities depending on the possibility of placing them at different positions in each project phase. A fixed facility is static and set at a specific location for the total project duration based on the site circumstances and the planner's decision. Meanwhile, the position of a non-fixed facility is not predefined and should be optimized to meet the planners' requirements.

Optimized solutions should satisfy predefined rules and standards when optimizing any objective function. In site layout planning, there are two main types of constraints: hard and soft constraints. Hard constraints represent the geometric relationships between the positions of TFs [27]. They include boundary, overlapping, distance, orientation, and zone constraints. Soft constraints in site layout express the planner's preferences as proximity weights and relocation weights [28].

3. Methodology

The methodology used in this study consists of three main stages: (1) a systematic literature review; (2) quantitative analysis using SNA; and finally (3) reporting on the study's findings. Figure 1 depicts the interconnected multi-stage framework employed in this study, encompassing both qualitative and quantitative methodologies. Initially, a systematic literature review (SLR) was undertaken, surveying publications in this domain spanning from 1995 to 2022. Subsequent to this review, the key parameters crucial for a proficient layout plan were extracted from the articles, serving as the foundation for the SNA. This ensuing analysis prioritizes each component based on its prominence (frequency) within the literature. Drawing from these findings, the study pinpoints overlooked layout parameters, thereby illuminating the knowledge gaps in this discipline. Informed by this quantitative examination, the authors propose a framework aiming to bridge these existing gaps in the CSLP research.

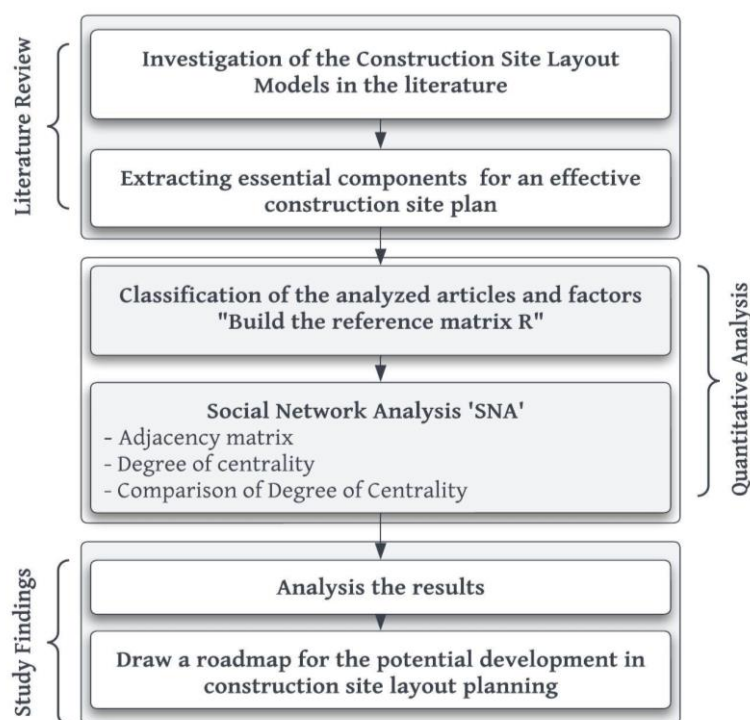


Figure 1. Study framework.

3.1. Systematic Literature Review

In this investigation, a systematic literature review (SLR) was applied adhering to the methodology proposed by [29]. SLR is a rigorous approach used to collect data and report on a specific topic and has been used extensively across various disciplines. It consists of five primary steps: the formulation of research questions, identifying inclusion and exclusion criteria, conducting quality assessment, collecting data, and lastly performing the descriptive analysis. Subsequent sections provide an in-depth explanation of each stage as employed in this study.

3.1.1. Formulating the Research Questions

This includes outlining the questions that the research sets out to answer. The research questions in this study are:

R.Q.1 What are the parameters that should be considered in construction site layout planning?

R.Q.2 What are the gaps in the literature in the area of construction site layout planning?

3.1.2. Identifying Inclusion and Exclusion Criteria

In this paper, a keyword search was conducted using the following search string: “construction site planning” or “site layout planning” and “optimization algorithm” or “construction site management”. These keywords were used to target all recent CSLP studies that either proposed a model using an optimization algorithm or studied CSLP from a site management perspective using other techniques. After collecting the publications, the authors examined the abstracts to determine their fitness for the research scope.

3.1.3. Collecting Data

Data were collected through the Scopus and Google Scholar databases using the inclusion/exclusion criteria previously identified. This resulted in over 600 articles, which were filtered using the criteria established in the previous step. The data collection step of the SLR was then conducted as a final quality check for the articles before proceeding to the analysis and reporting step (step 5 of the SLR).

3.1.4. Conduct Quality Assessment

This assessment was conducted to ensure that all identified papers were relevant and valid to the study. The authors conducted this step along with two independent researchers and the results were compared until there was no dissent. The method applied here was a coding scheme used by [30] for each of the identified papers to ensure that they discuss the research aim, methodology, data collection, and findings. The articles passing from this stage were used for the final step of the SLR to report on the topic. According to the conducted literature review selection, after the inclusion/exclusion criteria were applied, the authors identified 70 articles for this study between 1995 and 2022 (Table 1). These articles discussed the essential parameters considered under the umbrella of CSLP.

Table 1. Retrieved articles from the literature.

Year Range	Articles	Number
1995–2000	[31–37]	7
2001–2010	[19,38–57]	21
2011–2020	[1,2,14–17,20,21,24,58–85]	37
After 2020	[28,86–89]	5

3.1.5. Perform Descriptive Analysis

The literature from 1995 to 2022 in this domain was reviewed extensively. Key components for effective construction site layouts were extracted from these articles and analyzed using SNA to gauge their coverage. This analysis prioritized components by their frequency in the literature, revealing overlooked layout parameters. The final phase of the SLR informed the subsequent social network analysis, discussed in the next section.

3.2. SNA Application

In this study, SNA was employed to dissect intricate construction subjects like CSLP. The application of SNA was structured as a multi-step process. Initially, SNA was used to scrutinize the domain of literature publications, pinpointing leading works via a co-referencing SNA diagram (Figure 2). Within this diagram, each node symbolizes a research article, denoted by its primary authors and publication year. The edge (or link) between any two nodes indicates a citation relationship between the articles. The size of each node reflects the citation frequency of the respective article. This network effectively led to the most impactful literature, from which the authors extracted essential concepts, objectives, optimization methods, identified gaps, and key parameters.

Figure 3 illustrates the second application of SNA in this research, focusing on the frequency of keywords within the literature to highlight the primary and recurring terms within the CSLP knowledge domain. In this depiction, each node corresponds to an author keyword from the sourced articles, with edges indicating the co-occurrence of keywords within the same article. The node size is proportional to the keyword's recurrence in the literature. Based on the derived degree of centrality (DC) measures, the terms "Optimization", "Genetic Algorithm", "Construction Site Layout Planning", "Construction Management", and "Construction Sites" emerged as the most frequently cited keywords, helping to shape this area of study.

SNA was then applied to analyze the key components, optimization algorithms, optimization objectives, and critical parameters. This was done to calculate the degree of centrality (DC) for each reference. The following sections elaborate on the study framework, analysis, recommendations, and conclusions.

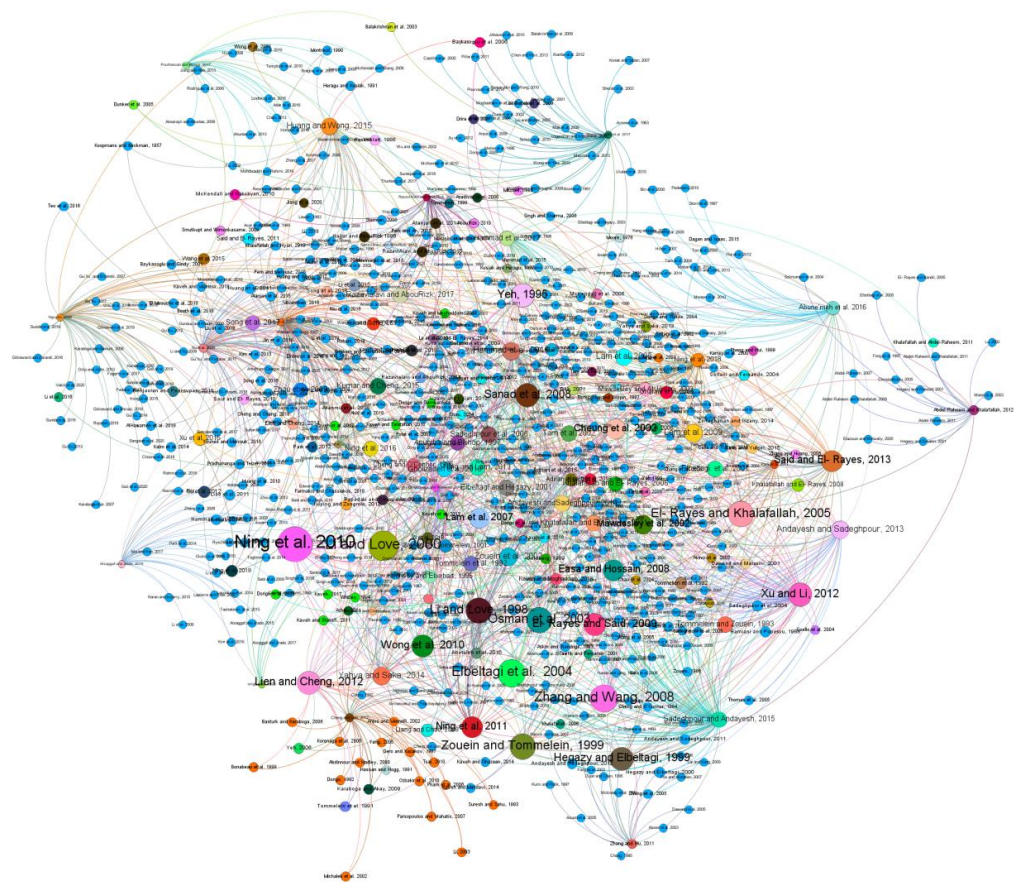


Figure 2. Co-referencing SNA diagram.

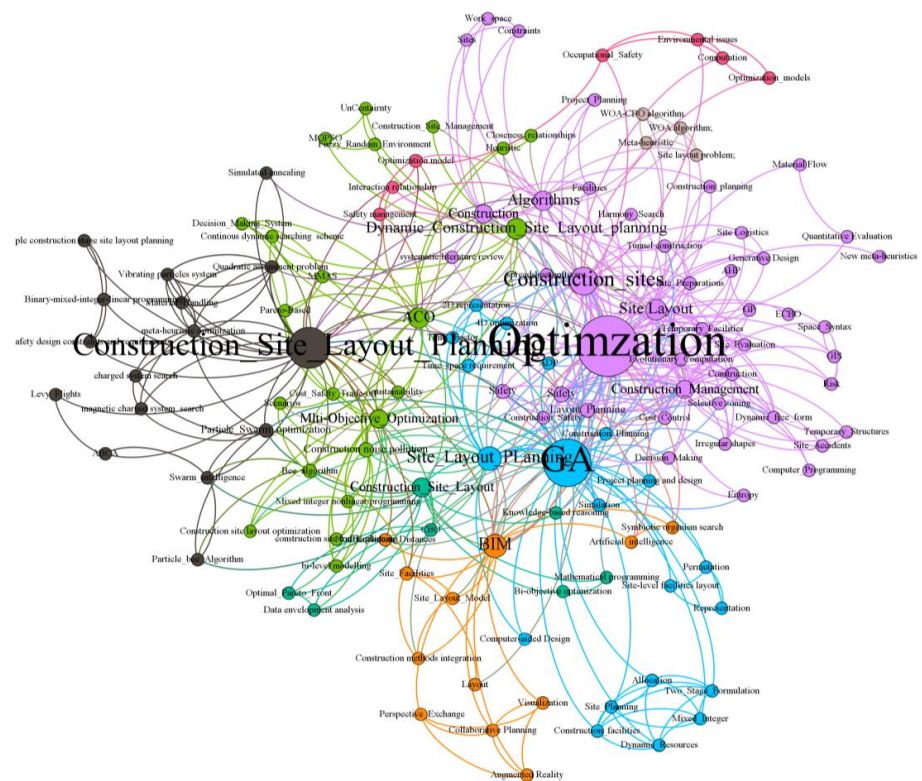


Figure 3. Keyword occurrences in the literature.

4. Construction Site Layout Planning

The authors undertook a comprehensive analysis of the collected research articles. Table 2 lists the key components essential for CSLP extracted from the SLR. Figure 4 depicts a network of the extracted layout parameters, where the size of each node represents how often they appear in the 70 articles. The network shows that most of the literature has predominantly focused on developing a static site layout model that defines approximate facility shapes and targets to minimize total transportation costs in continuous or predetermined spaces, assuming Euclidean distances.

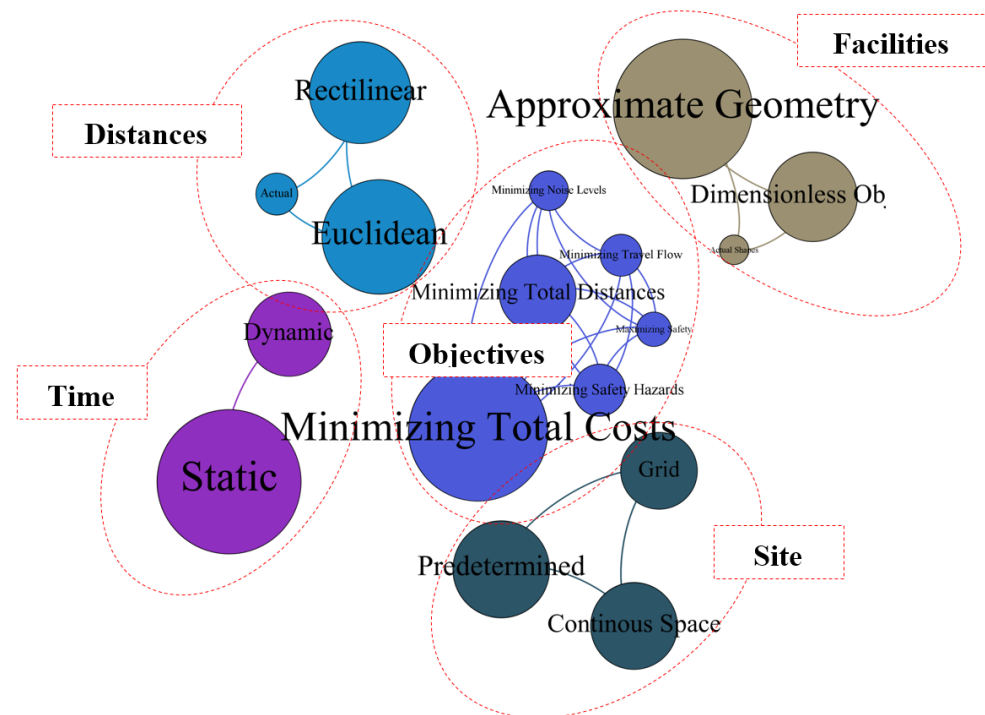


Figure 4. Key CSLP components network diagram.

4.1. CSLP Optimization

According to [1] CSLP is an activity of the planning process that determines the optimal locations of TFs to improve the construction process efficiency. It concerns the optimization process, in which the site planner searches between multiple solutions to find a suitable one. Multiple optimization algorithms have been employed in previous research to address the layout planning problem, categorized into two main branches: mathematical approaches, which are exact algorithms, and heuristic techniques, which are approximate algorithms. Mathematical approaches aim to find the optimum solution by identifying a primary target “objective function”. However, according to [53], mathematical approaches are confined as they require more computation and are applied to small-scale layout planning problems [90]. Heuristic algorithms search for near-optimal solutions within a reasonable time and amount of effort. No significant difference exists between optimum and near-optimum solutions, as any exact solution still needs some enhancements to match unforeseen conditions [41]. Li and Love [33] proposed a genetic algorithm (GA) model to optimally allocate site facilities. The research concluded that GA is a very efficient tool for solving CSLP. Cheng and Kumar [24] developed a dynamic site layout model that automatically creates layout models based on the building information modeling (BIM) site data and project schedules. They applied the A* algorithm to search for the shortest path between site facilities. Salah et al. [28] developed a generative design (GD) model to automatically generate layout plans to solve dynamic CSLP problems. The model proved its efficiency when compared with previous models.

Table 2. Review of different layout components considered in the literature.

Article	Research		Optimization Algorithm	Site		Facilities			Objectives					Distances			Time		BIM Application		
	Journal Paper	Conference		Predetermined	Grid	Continuous Space	Dimensionless Objects	Approximate Geometry	Actual Shapes	Minimizing Total Distances	Minimizing Travel Flow	Minimizing Total Costs	Minimizing Noise Levels	Maximizing Safety	Minimizing Safety Hazards	Euclidean	Rectilinear	Actual		Static	Dynamic
[32]	x		ANN	x			x					x					x		x		
[33]	x		G.A	x			x			x							x		x		
[39]	x		GA, FL		x			x		x						x			x		
[19]	x		GA			x		x		x							x		x		
[16]		x	Electimize		x			x		x							x		x		
[24]		x	GA and A*		x			x				x						x		x	x
[64]	x		NSGA II			x		x				x		x		x			x		
[65]	x		MOABC + LFA			x		x				x			x		x			x	
[15]	x		GA			x		x		x								x		x	
[14]	x		GA			x		x						x		x			x		
[68]	x		GA	x				x				x					x		x		
[71]	x		GA			x		x				x				x				x	
[79]	x		GA	x			x					x				x				x	
[1]	x		LP	x			x					x			x		x		x		
[28]	x		GD			x		x				x					x			x	x
[86]	x		MOPSO		x			x				x	x			x				x	x

Figure 5 shows a network diagram for the applied algorithms in the studied articles. The size of each node indicates the number of repetitions in the literature, and the edge indicates the occurrence of the two nodes in a single piece of research. This network shows that GA is the most popular optimization algorithm in the literature. All of the studied and discussed algorithms and their abbreviations are explained in Table 3.

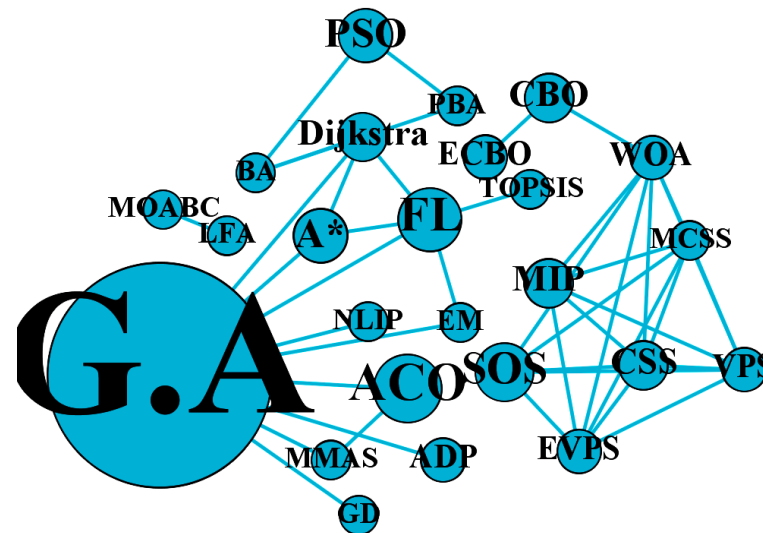


Figure 5. Optimization algorithms network diagram.

Table 3. Abbreviations of algorithms discussed.

Abb.	Abbreviation	Abb.	Abbreviation
ACO	Ant colony optimization	LP	Linear programming
ADP	Approximate dynamic programming	MCSS	Magnetic charged system search algorithm
ANN	Annealed neural network	MIP	Mixed integer programming
BA	Bee algorithm	MMAS	Max min ant system
CBO	Colliding bodies optimization	MOABC	Multi-objective artificial bee colony
CSS	Charged system search algorithm	MOPSO	Multi-objective particle swarm optimization
ECBO	Enhanced colliding bodies optimization	NLIP	Non-linear integer programming
EM	Entropy measure	NSGA-II	Non-dominated sorting genetic algorithm
EVPS	Enhanced vibrating particles system	PSO	Particle swarm optimization
FL	Fuzzy logic	PBA	Particle bee algorithm
GA	Genetic algorithm	SOS	Symbiotic organisms search
GD	Generative design	VPS	Vibrating particles system
LFA	Leavy flight algorithm	WOA	Whale optimization algorithm

4.2. CSLP Objectives

CSLP primarily focuses on minimizing the total project costs (transportation and TF relocation costs) while simultaneously maintaining other objectives such as site safety and environmental considerations [79]. This emphasizes the importance of the clear identification of potential hazards on construction sites. The complexity of CSLP arises from all the targeted criteria that might be at odds. For instance, maximizing a facility's safety increases its distance from other facilities. However, increasing this distance would maximize transportation costs and maneuvering duration. Multi-objective optimization seeks to find optimal solutions for two or more conflicting objectives [56,61,71,78]. In such optimization problems, the challenge lies in determining an optimal decision amidst diverse conflicting objectives. Multiple optimal solutions may exist, necessitating a trade-off among various objectives. Multi-objective site layout optimization models may include two or more of the following objectives:

- Minimizing Total Distances (O1).

- Minimizing Travel Flow (O2).
- Minimizing Total Costs (O3).
- Minimizing Noise Levels (O4).
- Maximizing Safety (O5).
- Minimizing Safety Hazards (O6).

Figure 6 shows a network diagram of the targeted objectives in the literature. The node size indicates the repetition times, while the link indicates a multi-objective study that targets the two indicated nodes. As concluded from this network, minimizing total transportation costs is the most common optimization objective in the CSLP literature.

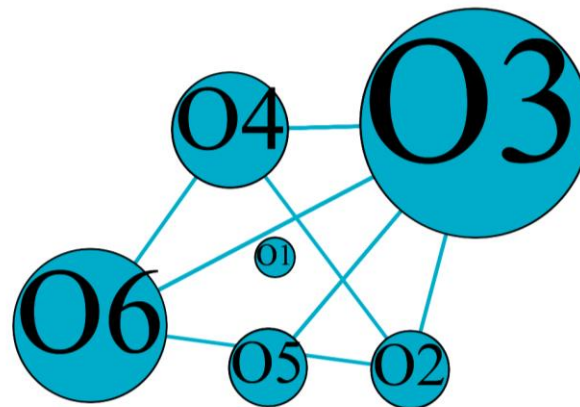


Figure 6. Optimization objectives network diagram.

4.3. Knowledge Gap

After this intensive review of the CSLP body of knowledge, numerous gaps in the literature were found. Previous research has focused on developing various mathematical algorithms and ignoring the required techniques to collect, calculate, and analyze different quantitative data sets to solve and model the problem. Most researchers assumed user-defined data. Hence, based-frame approaches still need to leverage technological tools for collecting required data such as actual traveling paths, expected travel frequencies, financial budget costs, and scheduling data. Advanced technologies could be better applied for modeling, visualizing, and exchanging information among the project actors. Previous models should have considered other essential criteria of CSLP, such as reducing noise levels inside and outside the project space, maximizing safety and minimizing hazard sources, minimizing environmental impacts, and waiting times. They have ignored actual paths and shapes, assumed predetermined locations or grid representations, or consumed much time and computational effort. Table 4 represents a summary of the previous literature limitations.

Table 4. Limitations from the literature.

Research	Limitations
[32]	Unequal-area QAP
[33]	
[34]	A static model with grid representation that considers Euclidean distances.
[31]	A single objective model with approximate TF shapes and distances.
[56]	The results are less accurate than later models.
[57]	Grid representation with approximate TF shapes and distances.
[59]	A single objective model with rectilinear distances and predetermined locations.
[60]	Predetermined locations that did not consider the facilities' sizes and actual transportation paths.

Table 4. Cont.

Research	Limitations
[16]	A single objective static model with grid representation and approximate TF shapes. Euclidean distances are considered.
[61]	The study only considered the comparison without practical implementation in a real complex problem.
[62]	Presented the TFs as bounding circles with unreal travel paths and targeting only to minimize transportation distances.
[78]	Single objective static QAP with rectilinear distances and dimensionless TFs.
[2]	A single objective model considered TFs as bounding circles with unactual paths.
[63]	Grid representation limits the model's capabilities with an approximation of TF shapes and distances.
[24]	A single objective model with grid representation limits the model's capabilities.
[15]	A single objective model where free-form shapes may not represent the actual available dimensions for TFs.
[14]	A single objective model with approximate TF shapes and Euclidean distances.
[68]	Predetermined locations and approximate representation of TFs and distances.
[71]	A single objective model with approximate TF sizes and Euclidean distances
[72]	Predetermined locations with dimensionless TFs and Euclidean distances.
[1]	
[73]	Static-single objective model with approximate sizing of TFs and distances.
[74]	A static model with approximate grid representation of TFs and distances.
[58]	Predetermined locations with dimensionless TFs and rectilinear distances.
[84]	
[83]	
[28]	Did not consider the actual travel paths.
[27]	
[86]	Grid site and approximate TF representation with Euclidean distances

The table indicates that some of the past models went through very simplified identifications and assumptions such as building only a single objective model [16,24,31,59,62], approximate facilities representation ignoring actual shapes and dimensions [31,57,60,62,63], and static models ignoring the complex dynamic nature of construction sites [34,73]. The quadratic assignment problem (QAP) is another limitation in the past literature models. In this type of problem, the site planner tries to allocate predefined TFs to some predefined site spaces regardless of the facilities' dimensions or actual travel paths [27,32,33,78]. There is a solid research base addressing CSLP in the literature. However, per the authors' reference, no acknowledged model could be applied globally in this knowledge area. To that end, the current study tries to identify a list of essential CSLP parameters that should be considered in any future model to be an effective tool for planning the construction site optimally. Then, the study draws a road for future research for more effective practices.

4.4. CSLP Parameters and SNA

After the literature review, the authors extracted some parameters essential for planning an efficient site layout plan suitable for various construction projects (Table 5). According to the components in Table 2 and the research gaps extracted from this body of knowledge, the authors concluded with 14 parameters, classified into four main categories (construction site; optimization process; building information modeling; and construction project). Table 6 describes each factor in more detail.

Table 5. Essential parameters for CSLP.

ID	Parameter	ID	Parameter
Construction Site		BIM	
P1	Modeling a continuous site space	P8	Application of BIM in planning
P2	Considering the site's surrounding environment	P9	Modeling existing obstacles on-site
P3	Main and secondary traffic roads for project gates	P10	Modeling actual travel routes
Optimization Process		P11	Actual facilities representation
P4	Choosing an effective algorithm	Construction Project	
P5	Reducing travel distances	P12	The project schedule for a dynamic plan
P6	Maximizing construction safety	P13	Required temporary facilities for construction
P7	Minimizing noise level on and outside the site	P14	Resource schedule plan

Table 6. CSLP parameters explanation.

No.	Parameter	Description
P1	Modeling a continuous site space	An effective layout model should consider that each point on the construction site space area is available to allocate site facilities.
P2	Considering the site's surrounding environment	The environment and building types around the construction site increase the site planning complexity. An efficient plan cannot allocate noisy facilities such as workshops near a hospital, school, or even a residential building.
P3	Main and secondary traffic roads for project gates	Optimum allocation of project gates (main and secondary) is essential for an effective work environment, and this should be done by identifying the main traffic road connecting to the site. Most of the literature assumes the gates as predetermined before the planning.
P4	Choosing an effective algorithm	Applying a strong and effective algorithm would make the planning model capable of reaching the optimum layout plans effectively (cost–time–computational effort)
P5	Reducing travel distances	A good layout should reduce travel distances between site objects and facilities and minimize transportation costs and redundant trips.
P6	Maximizing construction safety and minimizing site hazards	One of the main objectives of the CSLP optimization model is to maximize construction safety and reduce hazard sources for the laborers on site and the environment surrounding.
P7	Minimizing noise level on and outside the site	Recently, the noise pollution level has become an affecting parameter in construction site planning in society. Intensive residential areas are more sensitive to any construction project within its space. The pollution of this noise also affects the construction laborers themselves, which may cause lower production rates and more health issues.

Table 6. Cont.

No.	Parameter	Description
P8	Application of BIM in planning	BIM is the revolution that moved the construction sector ahead of its traditional modes. Applying all construction planning and design phases including layout planning would be a big step forward.
P9	Modeling existing obstacles on-site	Modeling actual travel routes between actual facilities representation with their real sizes with maneuvering around site obstacles should be the target for all layout models.
P10	Modeling actual travel routes	
P11	Actual facilities representation	
P12	The project schedule for a dynamic plan	Construction projects are dynamic, which forces the layout designers to consider the schedule of the project in the design.
P13	Required temporary facilities for construction	Each construction project is unique and needs various temporary facilities. The layout designers should be aware of all the required temporary facilities with their types, properties, manuals, and sizes.
P14	Resource schedule plan	A dynamic project requires various types of resources during each time period during its construction stage.

4.5. Developing the SNA

In this study, the quantitative analysis is conducted through SNA. It is a mathematical analysis that follows the graph theory approach, where various factors can behave considering their interconnectivity on a network diagram [91]. SNA is essentially applied to convert data into knowledge. It contains nodes that represent studied factors, and edges that represent their relations. *DC* is an essential characteristic that identifies the connected edges to each node [92]. Nodes with a higher *DC* have a higher number of edge connections giving more intensive quantitative analysis measures. The analysis starts with building a reference matrix ‘R’ with 14 rows (the extracted parameters) and columns (the retrieved articles). Each cell would equal “1” when the parameter in its row is considered in the article in its column; otherwise, it would equal “0” (Figure 7).

The next step is formatting the adjacency matrix by multiplying the reference matrix ‘R’ by its transpose (the result is a 14×14 matrix). All the resulting matrix’s diagonal values are replaced with zeros [11]. The *DC* of each parameter is calculated according to Equation (1).

$$DC_i = \sum_j V_{ij} \quad (1)$$

where:

- DC_i : the degree centrality for each parameter i ;
- V_{ij} : the cell value (row i and column j).

Parameters	Articles					
	A1	A2			An	
	P1	1	1	0	0	0
	P2	0	1	0	1	1
		0	0	1	0	0
		1	1	0	1	0
	Pm	1	0	0	0	1

Figure 7. Reference matrix 'R'.

5. Results and Discussion

As explained earlier, the authors compiled 14 parameters from 70 published articles in CSLP (1995–2022). The Gephi 0.9.2 version 3.0 software was the SNA environment used to conduct this analysis. After building the adjacency matrix, it was exported to the SNA for analysis. Figure 8 shows the resulting SNA diagram for the studied parameters, where the node size represents its weighted DC. The results show that “actual facility representation” is the most ignored parameter in the literature, as it has the lowest centrality score. Also, the analysis indicates that “choosing an effective algorithm”, “reducing travel distances and flows”, and “required temporary facilities for construction” are all common parameters in the literature as they have the same highest centrality score. That indicates their criticality for any layout model. Table 7 represents the rank (descending) of all the studied parameters according to their DC concluded from the SNA. The table shows that the optimization process is the most popular category in the literature. This indicates that the past research articles focused on searching, developing, or comparing various optimization algorithms to solve the layout problem (covering parameters P4 and P5). Construction projects and construction sites ranked second and third regarding their importance in the literature. This shows the importance of the parameters connected with the construction project as a whole and as a process. These two categories cover the area related to the project resource requirements and the site itself, representing the most critical components in any CSLP model.

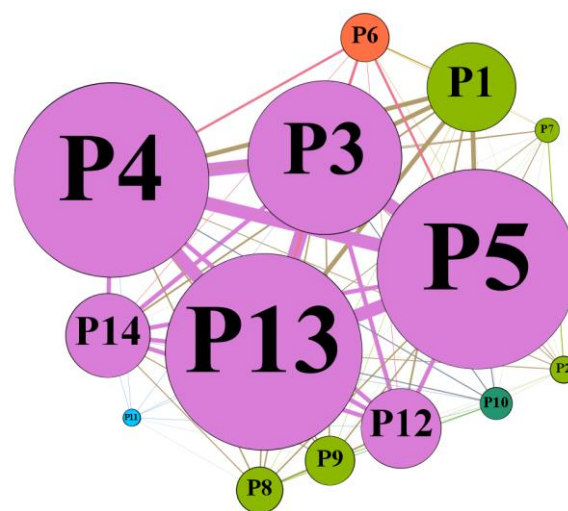


Figure 8. CSLP parameters SNA diagram.

Table 7. Ranked CSLP parameters.

Rank	Parameter	Category	ID
1	Choosing an effective algorithm	Optimization Process	P4
	Reducing travel distances and flows		P5
2	Required temporary facilities for construction	Construction Project	P13
	Main and secondary traffic roads for project gates	Construction Site	P3
	Modeling a continuous site space		P1
4	The project schedule for a dynamic plan	Construction Project	P12
	Resource schedule plan		P14
5	Maximizing construction safety and minimizing site hazards	Optimization Process	P6
6	Application of BIM in planning	BIM	P8
	Modeling existing obstacles on-site		P9
	Modeling actual travel routes		P10
8	Considering the site's surrounding environment	Construction Site	P2
9	Minimizing noise level on and outside the site	Optimization Process	P7
	Actual facilities representation	BIM	P11

The results show that the most highlighted factors are connected and essential for any layout model. Choosing a practical algorithm, minimizing travel distance onsite, and providing a full explanation of all required facilities for construction are the three main parameters for an efficient layout model, based on previous literature. However, the results show that most of the literature have not paid much attention to the actual facility representation, noise effects, or the influence of construction on the surrounding environment. Hence, this research gap is necessary to be addresses by researchers to be able to apply new technologies in this era of revolution 4.0.

6. Future Directions and New Trends

According to the conducted analysis of the literature, there are several new directions and potential improvements for future research in the field of CSLP. Firstly, many research questions should be answered and further examined, such as: what are the crucial objectives in layout planning? Are there any new and straightforward algorithmic methodologies to handle the optimization process? How would the site objects, routes, and facilities be modeled in a more realistic simulation manner?

According to this study, the multi-objective optimization problem requires more applications. The noise pollution criteria within construction sites should be addressed in a more detailed and effective manner. Occupational health and safety considerations in the literature are limited and need a new entrance for effective research. An explicit algorithmic representation of the layout optimization problem is essential to reduce the process complexity and make it more applicable. Figure 9 proposes a framework for future research in this area of knowledge based on reviewing the literature and defining all the main parameters of CSLP. It shows a four-step framework, starting from the input data, objective definition, optimization process, and, finally, output stage. The required data as inputs to any model are the site's multiple components including site dimensions, facilities' properties, and the schedule to address the construction dynamics. After collecting all necessary data, the model should be developed with a suitable optimization algorithm that can target all necessary objectives while maintaining site-identified constraints. After that, the optimization process takes place to produce layouts that meet the constraints and objectives to finally select the near-optimum layout model from the site planner's perspective.

Many artificial intelligence technology trends would have a significant impact on CSLP. Incorporating new BIM technologies to model, optimize, visualize, and simulate the site layout problem and to also check the applicability of generated layouts and detects clashes would be beneficial. Simulating and visualizing the construction process converts the problem from a mathematical representation into a realistic industrial problem with more conflicting goals. Using the new BIM generative design (GD) engine for optimization can

push layout planning to new levels of sophistication. Also, presenting augmented reality (AR) as a decision support for site planners would help mitigate the exerted psychological endeavor to understand the generated layouts and the process from a clear perspective for all practitioners.

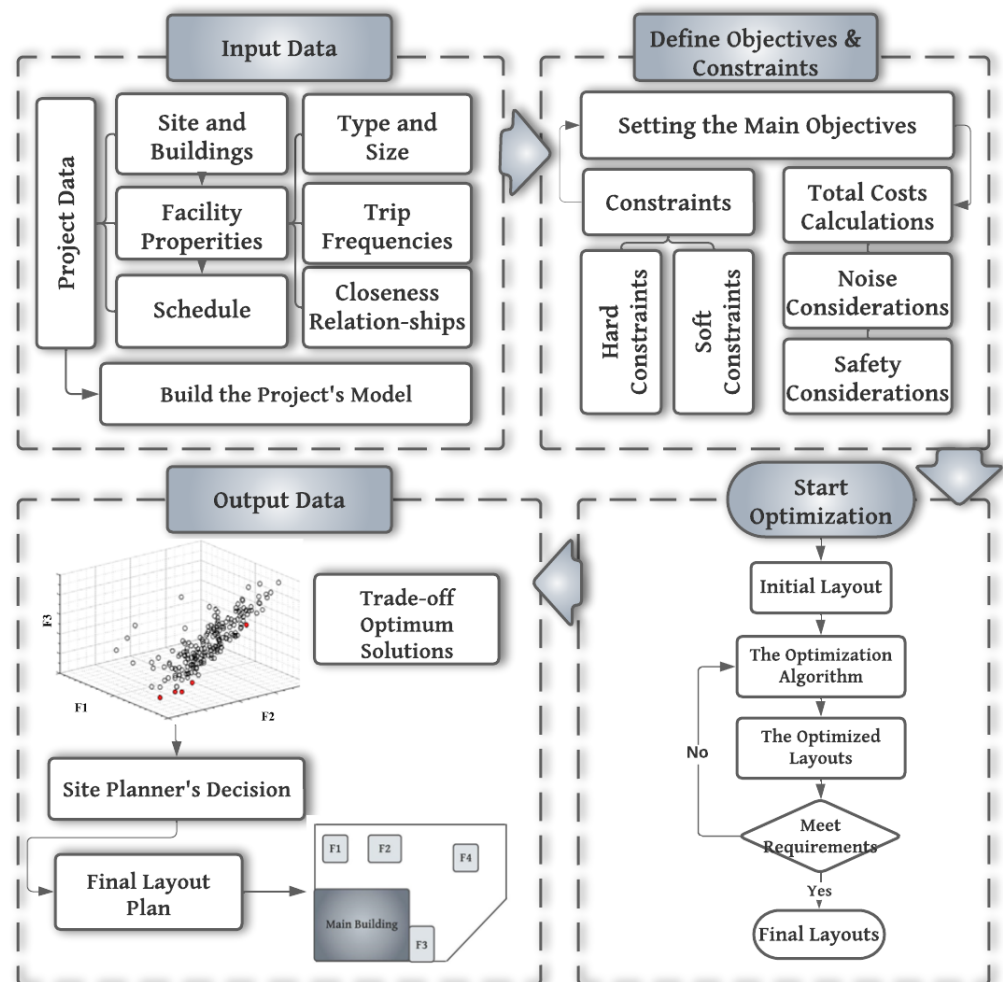


Figure 9. A proposed framework for future research.

7. Summary and Conclusions

This research presents an exhaustive examination of the extant literature on CSLP via a rigorous systematic literature review complemented by SNA. This investigation delineates the chronological progression and emergent trends within the CSLP domain, emphasizing the methodologies that were created to simulate operational construction conditions. The results indicate an increasing interest in optimization algorithms with a new trend in shifting toward BIM and artificial intelligence paradigms within CSLP. Due to the diverse parameters considered in previous research, the authors conducted a close analysis of the 70 publications focusing only on CSLP as a main research objective. The paper has traced the essential parameters in layout planning and modeling and reviewed possible approaches to define the site layout problem. Nevertheless, several recommendations can be made for future research based on observed limitations. The choice of databases and selection criteria might have biased the authors' results. The views expressed, especially about key parameters and identified gaps, are based on the authors' review of the identified 70 articles.

Future research directions can be suggested based on this review. Regular updates to this review will keep it current and widening the search for literature could offer deeper insights. There is also significant potential in testing and comparing between the best CSLP methods identified and evaluating their real-world effectiveness. Combining CSLP methods with new technologies like AI, or gathering feedback from industry experts can provide a broader understanding of the topic.

In summary, this paper adds to the academic discussion on CSLP, explaining its complexities and tracing its development. It reviews past research, highlights known limitations, and suggests paths for future studies. This work acts as a guide for both researchers and industry professionals, aiding in the creation of efficient and comprehensive site layout plans.

Author Contributions: Conceptualization, M.S. and E.E.; methodology, M.S., R.K., E.E. and H.W.; validation, M.S., R.K., E.E. and H.W.; formal analysis, M.S., R.K., E.E. and H.W.; investigation, M.S., R.K., E.E. and H.W.; writing—original draft preparation, M.S., R.K., E.E. and H.W.; writing—review and editing, M.S., R.K., E.E. and H.W.; visualization, M.S.; supervision, R.K., E.E. and H.W.; project administration, M.S., R.K., E.E. and H.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data is contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

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